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MENSURATION OF TIMBER
AND
TIMBER CROPS

CARTER



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A
TREATISE
ON THE
MENSURATION OF TIMBER
AND
TIMBER CROPS.

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BY
P. J. CARTER,
INDIAN FOREST DEPARTMENT.



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INTRODUCTION.

THIS treatise appeared originally in the *Indian Forester*, and it was there explained that it was for the most part a compilation from various German text-books, special use having been made of the article by A. Ritter von Guttenberg in Lorey's "Handbook of Forestry" published in 1887. In the first instance the German originals were closely followed and special regard was paid to diameter measurements, which give more nearly the actual contents of logs and trees, and which are used on the continent of Europe by buyers and sellers of timber; but, since in England and India the contents of round timber are always calculated on the assumption that the sectional area of a log is deduced from the square of the quarter-girth, it has been thought advisable in the present edition to have regard to the established custom, and thus render this treatise of more practical value to the English and Indian student.

P. J. CARTER.

June 1892.

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THE MENSURATION OF TIMBER AND TIMBER CROPS.

Chapter I.

On the measurement of heights, lengths, sectional areas, girths, and diameters of stems and trees.

Instruments for measuring the heights of trees are of two kinds:—

- (i) those which give the height without calculation, their construction being based on the principle of similar triangles; and
- (ii) those which give the angles made with a horizontal line by the lines of sight to the top and foot of the tree.

Instruments of both classes are very numerous, but the two most convenient are—Faustman's Mirror Hypsometer, and Weise's Height Measurer. They both agree in having, at right angles to the line of sight, a sliding graduated rule, which, before an observation is taken, is so adjusted as to represent proportionally the distance of the observer from the tree to be measured, and from the top of which hangs a plummet. Moreover, on the body of the instrument, runs a graduated scale similar to that on the sliding rule, so that when the instrument is directed to the top or bottom of the tree, the plummet line crosses the scale at the point which gives the figure expressing the vertical distance of the top or bottom of the tree, as the case may be, above or below the height of the observer's eye. The difference between the two instruments is, that whereas, in Faustman's Hypsometer, this figure is at once read in a mirror as soon as the top or bottom of the tree is bisected by the instrument; in Weise's Measurer, which is always made of metal, the graduations of the scale form a succession of serratures, which

catch the plummet line and keep it in place until the figure indicated has been read.

For measuring lengths, graduated rules or tapes may be used. Where great accuracy is required, the length of a felled tree or log should be measured along, or parallel to, its axis, and not on its slopping surface.

The sectional area of a log or tree can very rarely indeed be obtained directly. In nearly every case the girth or diameter must be measured, and the area of the section determined as if the section were a circle. $\text{Area} = \frac{(\text{girth})^2}{4\pi} = \frac{\pi}{4} (\text{diameter})^2$ or according to trade custom $= \left(\frac{\text{girth}}{4}\right)^2$.

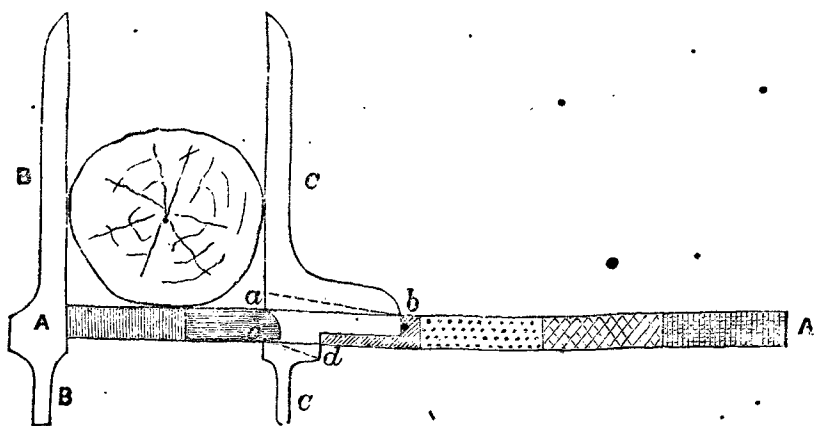
Girths are measured with tapes. It is convenient to have tapes graduated on both sides—one side for reading the girth, and the other for reading the corresponding diameter. The zero end of the tape should be furnished with a sharp metal point that can be easily fixed in the bark of the tree, so that one person may be able to measure any stem, no matter how thick it is. As a circle encloses a greater area than any other plane figure of equal perimeter, and as the sectional outline of trees is seldom quite circular, the contents of a log or tree calculated directly from its girth by the formula $\frac{(\text{girth})^2}{4\pi}$ will usually be in excess of the true contents.

Unless the contour of the log is circular, it is impossible to obtain by girth measurement the circumference of the circle which encloses the same space as the section whose area is required. Irregularities of outline, due to fluting, bark, etc., cannot be overcome in measurements of girth, whereas, as we shall presently see, they can more or less successfully be allowed for in measuring diameters. Experiments made in Baden prove that girth measurement yields a result that is from six to ten per cent. greater than that obtained by means of diameter measurement. It is, however, obvious that in cubing logs departing from the cylindrical form, the measurement of the girth is more to be relied on than the measurement of a single diameter.

When the true contents of a log are to be deduced from diameter measurement, that diameter should be sought which, considered as the diameter of a circle, gives a result as nearly as practicable

equal to the area of the section measured. When the section is elliptical, the mean of the longest and shortest diameters should be taken $\left(\frac{D+d}{2}\right)$, and the area of the section is then assumed to be $\frac{\pi}{4} \times \frac{D^2 + 2Dd + d^2}{4}$. Now as the real area of the ellipse is $\frac{\pi}{4} Dd$, the mode of measurement recommended gives an excess of $\frac{\pi}{4} \left(\frac{D-d}{4}\right)^2$, that is to say, an excess equal to the area of a circle whose diameter is equal to half the difference of the two measured diameters. Save in very exceptional cases, this difference is small enough to be disregarded. The area of sections of irregular contour can be determined from the mean of three diameters, but the result thus obtained will generally be found to be somewhat too high.

Diameters are measured with a calliper resembling, in all its essential parts, a shoemaker's measure. The pattern of calliper invented by Friedrich is one of the best. It consists of a graduated rule AA, to one end of which is fixed the arm BB. CC is a moveable arm capable of sliding backwards and forwards on the rule AA, which passes through the hole *a b c d* in it. To enable the arm to slide freely the hole is made oblique to its inner face, but in such a manner that as soon as it comes in contact with the log to be embraced, the arm is pushed back and rests perpendicularly on the graduated rule, with which it remains in contact only along the edges *b* and *c*.



In measuring logs and trees the following general rules are laid down for foresters on the continent of Europe :—

- (a) Diameters are to be preferred to girths.
- (b) In the case of elliptical or oval stems, take the mean of the largest and smallest diameters.
- (c) In the case of large stems measure at least two diameters.
- (d) In the case of stems of irregular contour, measure several diameters, and avoid all protuberances, etc.
- (e) Measure diameters and girths always in a plane at right angles to the axis of the stem.
- (f) If the place of measurement falls on an irregular part of the stem, measure the diameter or girth, as the case may be, at an equal distance on either side (above and below) of the irregularity, and take the mean of the two measurements.
- (g) Moss, etc., thick enough to vitiate the measurement of the stem should be removed.
- (h) If an accurate measurement of an irregular section is required, transfer its outline to tracing paper and compute its area with a planimeter or acre-comb.
- (i) Never be without tables showing at a glance the areas of circles for given diameters and girths.

In England and India diameters are rarely measured, as old established custom has prescribed that in the sale of timber the square of the quarter-girth should be regarded as the sectional area of the log or tree.

Chapter II.

On the measurement of Felled Trees.

The felled trees should be cut up in the usual way, that is to say, into logs and smaller pieces.

1. *Measurement of Round Timber.*

Several formulæ have been devised for the determination of the contents of round timber with more or less near approach to accuracy, but only two are of practical utility. These are,

- (i) $\frac{a_b + a_t}{2} \times l$ known as Smalian's formula; and
- (ii) $a_m l$ known as Huber's formula.

In the above l is the length of the log, a_b , a_m and a_t the sectional area of the log at the base, middle and top, respectively.

Both formulæ contain an error, the extent of which is proportionate to the amount of difference between the diameters at the top and base, respectively, of the log, that is to say, to its degree of taper; and this error increases as the square of that difference. Huber's formula always gives too small, and Smalian's too great, a result, the error of defect in the one case being one-half the error of excess in the other.

Huber's formula has also another advantage, for which it is to be preferred: the modes of measurement and calculation adopted in France and Germany give, as a rule, too high a figure for the sectional area concerned in each case. This excess is partly compensated for by the employment of Huber's formula, whereas the other would only exaggerate it.

In order still further to diminish error, long logs should be measured in two or more sections, the number of the sections increasing, *i.e.*, their length diminishing, with the taper of each log. The contents of those of regular shape and not exceeding 20 feet in length may, however, be deduced from their sectional area in the middle. Longer logs, even if of regular shape, should be cubed in two or three sections.

All large round logs should be measured singly.

If the logs are stacked so that they cannot be conveniently measured in the middle, the mean of the sectional areas at the base and at the top must be taken. The mean sectional area should never, under any circumstances, be deduced from the mean of the two girths at the two extremities respectively, or an error of from 10 to 15 per cent. may result.

Poles are seldom cubed singly; nearly always in stacks, built up of poles of one and the same length, and of approximately one and the same girth. Their solid contents are generally ascertained by inspection from special tables.

Straight and regular-shaped branches are measured in the same way as logs.

2. *Measurement of Square-cut Timber.*

Such timber must of course be cubed by the formula, length $\times$ width $\times$ thickness.

3. Measurement of Small Wood.

The solid contents of toppings and loppings, and of irregular-shaped pieces from stumps and roots, are obtained by the *water method* (being equal to the quantity of water they displace when submerged) or by the water-method and weighment combined. For the water-method special vessels, called *axylometers*, may be employed. In the combined system samples of each kind or class of wood are successively weighed and measured by the water-method, and the contents of the entire quantity in each class are then worked out by means of a simple proportion sum. Figures expressing specific gravity cannot be employed, since the specific gravity of wood varies not only according to the amount of moisture present, but even in one and the same tree according to the part from which it is derived.

The most rapid way of measuring small wood on a large scale is to stack it cut up into billets of one and the same length, the width of each stack being equal to the common length of the billets. The contents of a stack will be equal to length $\times$ height $\times$ common length of the billets. The length of a stack built up on a slope must be measured horizontally. The above formula will give us only *stacked* contents; to reduce these to *solid* contents, we must determine, by the water-method, or by the combined water and weighment method, the exact volume of a sufficiently large number of stacked units, thereby obtaining the ratio between *solid* contents and *stacked* contents. To obtain the *solid* contents of a stack we have then only to multiply the *stacked* contents by this ratio, which we may hence term a *reducing factor*. The following figures may be accepted as average reducing factors for converting stacked into solid contents:—

For split wood	.	.	.	.	0.60 to 0.80
„ round billets	.	.	.	.	0.50 „ 0.65
„ small stuff	.	.	.	.	0.30 „ 0.45
„ wood from stumps and roots	.	.	.	.	0.30 „ 0.40

In connection with the determination of the solid contents of stacked wood it is obvious—

- (a) That the longer the billets are, or the less carefully built up the stacks are, the less will be the solid contents.
In careless stacking billets often lie across one another.

- (b) That the thicker or more regular-shaped the billets are, or the more carefully built up the stacks are, the greater will be the solid contents.
- (c) That the larger the stacks are, the larger will be the reducing factor to be adopted.

4. Measurement of Bark.

When bark is sold separately, its quantity may be determined either by weightment or by ascertainment of volume. The solid contents are calculated by means of reducing factors in the same way as the solid contents of small wood. Experiments give from 0.3 to 0.4 as the average factors for bark. It has been found that the quantity of bark varies from 6 to 15 per cent. of the total volume of the tree or crop.

Chapter III.

On the measurement of Standing Trees.

In this case, unless ladders are used (a procedure that is hardly practical and is not really necessary) only a single diameter or girth can be measured directly, *viz.*, near the base of the tree. Any diameter above 6 feet from the ground must be measured indirectly by means of special instruments, the best of which are Winkler's and Saulaville's Dendrometers and Breymann's Universal Instrument. Obviously no direct measurement of the branches is practicable, and their cubical contents can, therefore, only be estimated from the results of special experiments, or with the help of long experience.

We have five different methods of estimating the contents of standing trees—

1. Ocular estimation, without any measurement at all.
2. Estimation with the help of *mass-tables*, the height and girth at breast-height being accurately measured.
3. Estimation with the help of *form-factors*, which serve to reduce, to the true contents of the tree or of any part of the tree, the volume of the cylinder, whose height is the height of the tree and girth the girth of the tree measured at breast-height.

4. Estimation by *richt*-height, in which, besides the girth at breast-height, the height at which the stem tapers down to half that girth is measured.
5. Estimation with the help of the height of the tree and several girths, the lowest of which is measured at breast-height.

1. *Ocular Estimation.*

Practised wood-cutters are able to estimate more or less accurately with the eye alone the contents of trees belonging to species that they are familiar with, and growing in localities with the peculiarities of which they are acquainted. It is needless to say that the most experienced are liable to commit large errors, and that the inexperienced should never employ this method.

2. *Estimation with the help of Mass-tables.*

The mass-tables drawn up with great labour for the forests of the kingdom of Bavaria give the cubical contents of trees of known height, diameter, and age-class. They comprise averages deduced from the measurements of 40,000 trees. On this account, although they give accurate results for a large number of trees taken together, they are not to be relied on for cubing trees singly, as the single tree in any given case may differ very widely from the average tree.

3. *Estimation by means of Form-factors.*

If a = sectional area of the trunk at breast-height, h = height of the tree, c = the true contents of the tree or tree-part considered, and C = volume of an ideal cylinder whose basal area is a and height h , then we have the following formulæ:—

$$c = fah, \text{ and } f = \frac{c}{ah} = \frac{c}{C},$$

where f is a constant termed the form-factor, and is deduced as an average from the measurement of a sufficiently large number of type trees. Type trees are selected, felled and measured separately for each age or size-class, and for each species or group of species.

Form-factors may be deduced, according to the requirements of the case, for the stem only, or for the whole tree, or for the timber

only, or for the branches, or for the roots, or for all and each severally.

In the formulæ above we have supposed that the girth and sectional measurements have been taken at the height of a man's chest above the ground, assumed, for the sake of uniformity, to be 4 feet 3 inches. But it is obvious that any other conventional height would serve the purpose, although it is usual and most convenient to employ the one we have adopted. We need refer to only one other convention which is sometimes used. The girth may be measured at a constant fraction (say, for instance, one-twentieth) of the height of the tree, in which case the form-factors obtained are termed *normal*. Normal form-factors yield perfectly correct results, but they are not practical owing to the difficulty and trouble of measuring at such various heights, many of which cannot be conveniently reached.

Form-factors are said to be *absolute* when the base of the ideal cylinder is assumed to be in the same plane as the girth which is measured. In this case the contents of the portion of the stem below the plane must be calculated separately.

Like mass-tables, form-factors give closer results for an entire forest than for individual trees.

The preparation of a complete set of form-factors requires great care and experience, as their correctness depends entirely on the selection of the type trees, whose dimensions serve as the basis of all the calculations. In some cases the trees of a crop have been classified into various classes according to their height and shape, and a separate form-factor calculated for each class. The most recent investigations prove that form-factors vary chiefly with the height of the trees.

4. *Estimation by richt-height.*

By the term *richt-height* we mean that height at which the stem of the tree measured has a diameter equal to half the diameter at some point near the ground. If h_r = the *richt-height* h_g = the height at which the diameter near the ground is measured, and a = the sectional area of the stem at this height, then, according to Pressler, the contents of the stem

$$= \frac{2}{3} ah_r + ah_g.$$

This formula is based on the fact that the first term represents

correctly the volume both of the cone and of the paraboloid, and is only 1.3 per cent. less than that of a cone with a concave surface.

The *richt*-height may be estimated with the eye, or obtained with the help of a special measurer (the *richt-tube*). This instrument consists of cardboard tubes telescoping one into the other. At the objective end of the outer tube are fixed two wire points at the extremities of one and the same diameter. The end of the innermost tube is closed, except for a small hole to which the eye is applied. To use the instrument, direct it on the trunk at the point where the diameter has been measured, and pull out the tubes until the wire points just embrace it. Then drawing out the tubes to twice this length, direct the instrument again on the tree, working it up along the trunk until the wire points just embrace it, and note the point where this occurs. The diameter at that point is, on the principle of similar triangles, half the original measured diameter, and the height of the point is the *richt*-height sought.

5. *Estimation by means of several diameters.*

The measurement of diameters above the reach of a man of average stature requires the use of special instruments, and hence this method is seldom employed.

6. *General.*

As the fourth and fifth methods can give only the contents of the stem, the contents of the branches and stump and roots must be obtained by means of special tables compiled for the purpose.

Chapter IV.

On the measurement or Valuation Survey of Standing Crops.

1. *The Various Methods of Valuation Survey in General.*

The most correct method of obtaining the cubical contents of an entire crop would be to cube each component tree separately, and then sum up the results. But such extremely detailed procedure is entirely impracticable, except in the case of crops of very limited extent. In practice, therefore, it is necessary to devise some much more expeditious methods that will yield results accurate enough for the purposes of the forester.

Without being guilty of any important error, we may assume that in one and the same crop trees of like girth and height do not differ greatly either as respects cubical contents or form-factor. Hence, we may divide the component trees of a crop into classes based on equality of diameter and height combined, and find the contents of each class by selecting trees fairly representative of that class (*sample or type trees*) and measuring these separately. The average contents of the sample trees, multiplied by the number of trees composing the class, will give very approximately the true contents of the whole class.

If all the component trees of a crop were of like height, diameter, and form, the measurement of a single sample stem would suffice. In reality, however, the trees of a crop are of unequal development, and must be divided into classes comprising individuals of equal diameter and height. Nevertheless, it may sometimes be possible in a more or less irregular crop to find a tree such that its contents are equal to the mean contents of all the trees comprising the crop. Such a tree we may term an *average tree*, and the method of measurement in which average trees are employed may accordingly be termed *Valuation by average trees*. Suppose c = the contents of the average tree, C , = the contents of the whole crop, and n = the total number of trees, then—

$$c = \frac{C}{n}$$

It is, however, rare to find a single tree such that its contents are equal to the mean contents of all the trees of the crop; while, on the other hand, the establishment of as many classes as there are different girths and heights present in the forest would involve enormous expenditure of time and labour. Hence the adoption of a middle course is to be recommended. Firstly, more comprehensive girth-and-height classes should be established, each class comprising trees not precisely of one and the same dimensions, but of different heights and girths varying between a maximum and a minimum that are sufficiently close together to ensure the necessary degree of accuracy; and, secondly, these girth-and-height classes being established, the average tree for each class should be obtained by calculation. For convenience' sake we may designate this method of measuring crops, *Valuation by means of girth-and-height gradations*.

Just as the contents of a crop or of a class may be taken as the product of the number of stems and the contents of the average tree, so we may also express it either as the sum of the basal areas of all the stems (A) $\times$ the average height of the crop (H) $\times$ the average form-factor (F) or as $A \times$ the average *richt*-height (H_r).

We have thus three formulæ—

- (i), $C = c n$... Valuation by means of the average tree.
 (ii), $C = A H F$... " " average form-factor.
 (iii), $C = \frac{1}{2} A H_r$... " " average *richt*-height.

For the first formula the sample stem measured must be such that its contents $= \frac{C}{n}$.

In using the second formula the height and form-factor of the sample stems measured must be identical with the average height and form-factor of the crop or height-and-girth class, a condition that is more easily realized than the equality demanded for the use of the first formula.

Of the quantities A , H , and F , the first is obtained at once by direct measurement of the girths of all the stems taken at a fixed height above the ground; while the other two are ideal, and must be obtained as accurately as possible by computation from the measurements of the sample stems.

In those methods of valuation survey which are based on the actually measured contents of sample trees and on the measured basal areas of all the trees, a fourth formula, derived from formula (ii), may be substituted for formula (i). Using the same expressions as before, and supposing that c , a , h , and f , respectively are the mean contents, basal area, height, and form-factor of the type or sample trees, we have—

$$C = A H F \dots \dots \dots \text{Formula (ii),}$$

$$\text{and } c = a \times h \times f \dots \dots \dots \text{by assumption;}$$

$$\text{Hence } C : c = A H F : a h f$$

$$\text{and as } H F \text{ is by assumption } = h f$$

$$\therefore C = c \frac{A}{a} \dots \dots \dots \text{Formula (iv).}$$

Formula (iv) is to be preferred to formula (i), for two reasons: firstly, because the important and easily obtained term A enters into it; and, secondly, because the sample stems have to furnish only the average height and form-factor, not the average contents, of all the trees of the crop or of the diameter-and-height class, so

that they need not be *average* trees in the strict sense of the word. After the measurements required to obtain the total basal areas of the trees have been taken, it only remains for the surveyor to select his sample trees properly and in suitable numbers for each girth-height class. By suitable numbers is meant a fixed proportion of the total number of trees in the respective classes, or equal numbers in case the several classes include more or less the same number of individuals.

The sample stems are usually felled in order to determine their contents; but their contents may be obtained without felling by means of volume-tables or of previously prepared tables of form-factors.

The methods of valuation hitherto described require that every tree in the forest should be measured. But the contents of the whole crop may also be calculated by means of a sum of simple proportion, from data furnished by sample plots in which alone the trees are measured.

But measurement of every kind may even be entirely dispensed, giving place either to ocular estimation, or to estimation by comparison with results obtained in similar crops elsewhere.

The following is a synoptical view of the various methods of effecting a valuation survey of a crop :—

I. VALUATION BY ACTUAL MEASUREMENT.

- A. Of every tree in the entire crop (*complete survey*).
- B. Of every tree only in sample plots (*survey by sample plots*).

Whether we undertake a complete survey, or only one by sample plots, we may ascertain the contents of the whole crop—

- a. By deducing it from the contents of type or sample trees, representing either—
 - α. The ideal average tree of the crop, or
 - β. The average of trees of one and the same girth and height, or
 - γ. The average of trees of comprehensive girth and height-classes (girth and height varying between a maximum and a minimum limit), *i.e.*, *girth and height gradations*.

Now whether we adopt method α , β or γ , we may obtain the contents of the sample trees either (1) by felling them and measuring them accurately, or (2) by estimating their contents standing. In either case, we may seek to ascertain one of two things: (i) the total solid contents of the trees, or (ii) separately the quantity of each class of wood or timber in them.

b. By means of the *richt*-height.

c. With the help of specially prepared tables of volumes (volume-tables) or of form-factors.

II. VALUATION WITHOUT ANY MEASUREMENTS (*eye survey*).

A. Ocular estimate, after observation either (*a*) of the whole crop, or (*b*) of sample plots.

a. Of the number of stems of different size-classes.

b. Of volume of material (1) per acre, or (2) standing in the whole forest.

B. Estimate based on examination of figures given in existing yield-tables prepared either—

a. Specially for the locality, or

b. For the forest district or region.

2. *Choice between Complete Survey and Survey by Sample Plots.*

The valuation survey of a crop by means of sample plots obviously requires very much less labour and time than a complete survey, and must therefore be adopted whenever it is likely to fulfil the objects of the survey. Its admissibility depends on three principal considerations:—

I.—THE PURPOSE OF THE SURVEY AND THE DEGREE OF ACCURACY DEMANDED.—The object of a survey is not necessarily always to ascertain the total contents of the crop: we may desire to know only how much material on an average there is on an acre, or we may seek to obtain figures required for the compilation of certain tables, or we may simply wish to determine the quality of the soil or locality, and so on. In all these latter cases the survey of well-selected plots, the area of which has been accurately measured, is preferable to the survey of

the entire crop, which will rarely be found to be of sufficiently uniform quality and composition throughout. Moreover, the area of a crop is often not exactly known. When great accuracy is required, as when the whole of a standing crop is to be put up to sale, it is of course advisable to measure at least the girth of every tree in the crop. Still it must be understood that, in the most carefully organized and conducted valuation survey, only a limited degree of accuracy is attainable, for although the girths or basal sections of the trees may be obtained with sufficient exactitude, the heights and form-factors of the trees can only be determined approximately. For carefully-framed working plans it is usual to make complete surveys, the procedure by sample areas being adopted only when circumstances render a complete survey difficult and at the same permit of sufficiently correct generalizations from the part to the whole.

II.—THE SIZE AND NATURE OF THE CROP.—Valuation survey by sample plots is obviously admissible only in crops that are so far uniform as to render it practicable to select certain portions presenting the average characteristics of the whole; but this method of survey is not justifiable if no time is thereby saved. Thus, if a crop is of limited extent, the whole of it can often be surveyed as quickly as a sample plot, which has to be carefully selected and then marked out and measured. So also in very open crops a complete survey is preferable, as it can be effected rapidly, and the sample plot, to represent the average of such a crop, must be comparatively large. We may lay down the following two rules for general guidance:—

1. In three cases the system of sample plots should be avoided—*Firstly*, in irregular crops of very variable density, or containing trees of very different girths in their different parts; *secondly*, in small crops not exceeding five acres in extent; and, *thirdly*, in very open crops, or in crops in which only certain scattered trees, such as coppice stores, large trees in an area under jardinage, have to be accounted for.
2. On the other hand in young crops or in coppice, where often 2,000 and even more stems may stand on an acre,

a complete survey is quite out of the question, and sample plots should be surveyed, if there are no volume-tables available to furnish the requisite data and dispense with the necessity of any measurements.

III.—IN A CERTAIN SENSE, ALSO THE NATURE OF THE GROUND.

—On gentle slopes the whole crop can be easily surveyed, but on steep or rough, rocky hill-sides, a complete survey would be difficult as well as expensive, and the adoption of sample plots would be justifiable.

3. *Selection and Demarcation of Sample Plots.*

It is hardly necessary to say that the sample plots should be as nearly as practicable a true average sample of the entire crop. Hence, before selecting it, the surveyor should go over the whole crop, so that its average character may become clearly impressed on his mind.

The following rules may be laid down for observance :—

- I.—No sample plot should ever be selected on the edge of the crop, for a true average will seldom be found there.
- II.—On slopes presenting a wide range of elevation, or in crops offering a variety of aspects and soils, several sample plots judiciously distributed, should be selected.
- III.—The form of the sample plot should be a long rectangle.
- IV.—The boundary of the sample plot should be clearly marked by blazing the trees immediately outside, or by splashing them with whitewash.
- V.—The aggregate area of the sample plots should be from 3 to 5 per cent. at least of the total area of the crop.
- VI.—In mature crops, no sample plot should be less than 1 acre in extent, and the minimum area should, as a rule, be 2—3 acres. In young uniform crops, containing a large number of stems, $\frac{1}{2}$ or even $\frac{1}{4}$ acre may suffice.
- VII.—In crops of large extent, several plots of 1—2 acres each are preferable to a single large plot.

4. *Enumeration Survey of the Crop.*

Before any attempt can be made to calculate the quantity of material in a crop, we must find out the number and respective

dimensions of the trees it contains, in other words, make an *enumeration survey*. In an enumeration survey of a mixed crop, the number and dimensions of the trees belonging to each species or group of species of similar habit should be ascertained and recorded separately; all important or extensively distributed species should be registered separately, the rest being classed into groups, each group comprising species that resemble each other in height and shape.

As regards the dimensions of the trees, their girth is always measured, the height, if that also has to be recorded, being estimated with the eye. Since in every enumeration survey an enormous number of trees has to be measured, it is not practicable to register the exact girth of each tree, but to group the trees into girth-gradations. The range of girth included in each gradation will vary with the size of the trees forming the crop and with the degree of accuracy sought. For the most accurate valuation survey, the following ranges are narrow enough:—

For a crop of	{ large trees . . .	3 to 6 inches.
	{ small trees . . .	2 „
	{ very small trees . . .	1 inch.

Supposing 1 inch has been fixed as the range, then every tree above $5\frac{1}{2}$ inches, but not more than $6\frac{1}{2}$ inches in girth, will be classed as being 6 inches in girth; every tree above $6\frac{1}{2}$ inches, but not more than $7\frac{1}{2}$ inches in girth, will be classed as being 7 inches in girth; and so on—that is to say, all fractions not exceeding one-half will not be taken into account at all, and all fractions exceeding one-half will be considered as 1. And so on with any other girth range. Here, in India, a girth range of as much as 18 inches, established by Sir Dietrich Brandis in Burma in 1859, has been made use of in most of our working-plans, and has been found to give sufficiently accurate data for the classes of forest we have to work, and for the rough methods of working them we are obliged to adopt.

As in extensive surveys it is generally found more convenient to use diameter callipers than to measure girths with a tape, the calliper should be marked in gradations of $\frac{1}{2}$ of an inch, or a foot, or other selected unit, so that the girth corresponding to measured diameter may be read on the calliper; the following precautions should however be observed. In crops consisting of fairly regular-

shaped and not very large trees the measurement of a single diameter may suffice, especially if, as tree after tree is gauged, the diameters of two successive trees are measured in different directions, more or less at right-angles to one another. Although a matter of petty detail, it is necessary to say that the callipers should be applied to the trunks of the trees properly, and the diameter or girth read off *before* they are removed. The diameters should be all measured at breast-height, and on hillsides this height should be taken on the upper side of the slope. Breast-height has been assumed to be $4\frac{1}{2}$ feet; but as the boles of trees do not taper either regularly or very rapidly, it is not necessary that this height should be exactly measured on the tree before the calliper is applied. Sufficient accuracy is attained if the measurer is careful to hold the calliper at the height of his chest and the diameter is measured at any height between $4\frac{1}{2}$ and 5 feet. When a tree divides into two or three main stems near the point at which the calliper should be applied, each stem should be measured separately.

The enumeration survey should be effected over successive narrow strips, each strip being gone over once and in a direction opposite to that in which the immediately preceding strip has been surveyed. On steep slopes it is convenient to run the strips horizontally and to begin at the bottom of the slope. The measurers, furnished with callipers, gauge the diameter of the trees and call out the figures read, which are at once noted in a properly-ruled field-book by the recorder, who is usually himself the surveyor in charge of the party. The number of measurers that can keep one recorder fully employed depends on the density of the forest, on the nature of the ground, on whether he is also in charge of the party, and on whether all or only certain classes of the trees composing the crop are to be measured. The number of measurers may thus, according to circumstances, range from 2 to 6, and even 7 and 8.

As the survey progresses the trees measured are immediately marked with a clearly visible blaze, which should not, however, be deep enough to expose the wood. In order to make the blaze, each measurer should be provided with a light short-handled axe. The blaze should be made on the side opposite the area still remaining to be surveyed, so that when the next strip is being surveyed the

men can at once recognise up to what point the strip just completed extends.

The duty of the surveyor in charge of the party is to see that the callipers are properly applied, the diameters or girths read before the callipers are removed, and the blaze made on the correct side. When a division into height-classes is necessary, the surveyor has also to judge with his eye the height-class of each tree as it is gauged. Hence the advisability of investing one and the same person with the duties of both surveyor and recorder.

The following is a sample of a convenient form of field-book—

RANGE.....					COMPARTMENT.....										
BLOCK.....															
Girth in inches at breast-height.	Species..... (or Height-class).					Number of trees.	Total basal area, in square feet.	Girth in inches at breast-height.	Species..... (or Height-class).					Number of trees.	Total basal area, in square feet.
30						43	16-797								
33						48	22-687								
36						26	14-625								
39						62	40-929								
42						56	42-875								
45						34	29-883	and so on							
48															

As the girth of each tree is called, a stroke is made in one of the compartments opposite the figure expressing that girth. The first four strokes are drawn upright, the fifth one obliquely across them. Each group of strokes thus represents five trees of the

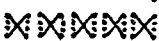
girth against which it is drawn. Each full compartment represents 20 trees, and the whole line of five compartments 100 trees of one and the same girth-class. After the survey is over, the total basal area of the trees of each girth-class is calculated and entered in the proper column. Lastly, the numbers of the trees and the basal areas are totalled up.

Perhaps a more convenient method of recording the number of trees is the one universally employed in France. It is as follows:—Each group, representing 10 trees, consists of two upright rows of four dots each, joined by two diagonal lines, which represent respectively the ninth and tenth trees, thus—

$$\times = 10; \begin{array}{c} \diagup \cdot \cdot \cdot \diagdown \\ \cdot \cdot \cdot \end{array} = 9; \begin{array}{c} \cdot \cdot \cdot \\ \diagup \cdot \cdot \cdot \diagdown \\ \cdot \end{array} = 8; \begin{array}{c} \cdot \cdot \cdot \\ \cdot \cdot \cdot \end{array} = 7; \begin{array}{c} \cdot \cdot \cdot \\ \cdot \end{array} = 6;$$

and so on

The subjoined form of field-book has been in general use in the North-West Provinces and Oudh for more than ten years, and can hardly be improved upon for enumeration surveys in which the classes include a large range of diameter and the forest is very irregular. Some of its advantages are (i) that it requires very little ruling, (ii) that it may be easily prepared from day to day by the recorder himself, and (iii) that, as the width of its different columns and compartments can, for that reason, be varied to suit the composition of the crop to be surveyed, a whole day's work, comprising several thousand trees, can be got into a single opening of the book. The total numbers of trees of each species (or group of species) and diameter-class is written in the right hand lower corner of its own compartment.

FOREST	BLOCK		COMPARTMENT		
Species.	Number of trees of diameter exceeding—				Total number of trees.
	6 inches,	12 inches,	18 inches,	24 inches.	
	but not exceeding—				
	12 inches.	18 inches.	24 inches.		
Sal,	 and so on 1,689				
Sain,					
Chir,					
Miscellaneous,					

5. Valuation Survey by means of the Average Tree.

The average tree, according to our assumption, is that tree whose height and form-factor are the same as the average height and form-factor of the crop, considered as a whole.

In order to obtain the average tree we must first of all determine what its girth is. This we shall know, if we know its basal area. If c , a , h , and f , represent respectively the contents, basal area, height, and form-factor of the average tree, then—

$$c = a h f;$$

But by formulæ (i) and (ii)

$$c = \frac{C}{n} = \frac{A H F}{n};$$

$$\text{Therefore } a h f = \frac{A H F}{n}$$

and $a = \frac{A}{n}$ (since by hypothesis $h f = H F$).

That is to say, the average tree is that tree whose basal area is the average basal area of all the trees of the crop. This being so, we can find out the girth of the average tree as soon as we know the number of stems composing the crop and their total basal area. Having obtained this girth, we fell and cube several trees of that girth, and the mean contents of these trees will be the contents of the average tree.

To obtain the above result, we have to assume that $h f = H F$. This assumption is, however, true only when (1) the heights and form-factors of all the trees in the crop, or, at least, the products of their heights and form-factors are equal, (2) these heights and form-factors, or, at least, their products, are proportional to the corresponding basal areas, and (3) the mean of all these heights and form-factors may be taken respectively as the height and form-factor of the crop as a whole. These three conditions can obtain only in very regular crops, and even in such crops as many as three or four of the trees of the average girth must be felled and measured in order to obtain a sufficiently close average for the contents of the average tree.

Resumé.—When this method of valuation survey can be adopted the following procedure should be followed:—Measure and register the trees in girth-gradations embracing a range of 1 inch. Then, with the aid of tables, calculate the aggregate basal area of the trees in each class, and total the whole. Divide this total by the number of trees, and the quotient will be the basal area of the

average tree. From this deduce the girth of such tree. Lastly, fell several type trees of this girth, and find out their contents accurately. The mean of their aggregate contents will be the contents of the average tree, and this, multiplied by the number of trees in the whole crop, or, which comes to the same thing, by the ratio of the total basal areas to the basal area of the average tree, will give the contents of the crop.

6. Survey by Girth or Height-and Girth-Classes.

In a forest crop there is never any constant relation between the heights, girths, and form-factors of the component trees. Of these three elements, two of them remaining the same, the widest fluctuations are presented by the girth, the other two varying within much narrower limits. In regular crops the average height of the stems comprised in each class varies directly as the girth of that class, the thicker stems being also the taller and *vice versa*; so that we may consider the height as a function of the girth. If the crop is very regular, the differences of height between the component trees will be so small that the height of the crop may be expressed by a single figure. In irregular forests, on the other hand, there can never be any constant relation between height and girth, for the thickest stem may be the shortest of all.

As regards form-factor, it may be regarded as a function of height and girth combined, for its variation depends on the same circumstances which govern the variations of height and girth and especially on the ratio of height to girth. Hence the form-factor may be assumed as being nearly equal for trees of like girth and height. But even in regular crops measurements of sample stems of one and the same girth may give differences of from 4 to 6 and even 10 per cent. in the form-factors.

We will now investigate the different conditions that may present themselves in the survey of crops or of a group of trees composing a girth-class, which may be regarded for the present purpose as a small crop by itself.

Starting with the element of girth, we have two broad cases: The girths of the trees may either (A) be different, or (B) be one and the same.

A.. GIRTHS DIFFERENT. Under this head we may have four separate cases as follows:—

(a) *Height and form-factor constant, i.e., form-factor a func-*

tion of height. We know that $a = \frac{A}{n}$ (page 21), and

$C = c \frac{A}{a}$ (formula iv, page 12). In other words

the sample tree of average basal section is a true average tree. This case obtains only exceptionally in a whole crop, but is always approximately true for the groups of trees composing its several girth-classes.

- (b) *Height and form-factor a function of the girth and hence variable, or height constant, but form-factor variable and a function of girth.*—The former contingency may, as a rule, be assumed as always prevailing in regular crops of one and the same age and origin; the former can very seldom happen. In either contingency only girth-classes should be adopted.
- (c) *Height irregularly variable, the form-factor being a function of height.*—In this case height-classes must also be formed.
- (d) *Height and form-factor both irregularly variable.*—This is generally the case in irregular crops composed of trees of various ages. Here also girth and height-classes must be formed, and in addition several sample trees should be measured for each class.

B. GIRTH CONSTANT. This is always true of girth-classes, and may be assumed to be true also of girth gradations.

We have three distinct cases as follows:—

- (a) *Height and form-factor constant or both of them functions of girth.*—In such a contingency every component tree would be a correct average tree, but this is never exactly the case even in the most regular crops.
- (b) *Height constant or a function of girth, form-factor variable.*—This is the case generally met with. In order to obtain a correct average form-factor several sample stems must be measured.
- (c) *Height variable and form-factor a function of height.*—In this case height-classes must be formed, thus reducing the conditions (for each height-class) to those of case (a).

The preceding detailed study indicates the several cases in which it is necessary to form only height-classes or only girth-classes, or combined height and girth-classes. Every crop to be surveyed must be divided up in this manner into a small number of distinct groups, for each of which the corresponding sample tree, possessing the average basal section, may be taken as a true representative in respect of both height and form-factor.

In the constitution of girth-classes one of three systems may be adopted, *viz.*—

- I.—THAT OF EQUAL GIRTH-GRADATIONS.—The number of gradations are usually from three to five, and the figures of the enumeration survey at once indicate the number of trees to be included in each gradation. In this system the disparity between the numbers of trees in the several classes is always very great.
- II.—THAT OF NATURAL SIZE-CLASSES.—In the most canopied crops at least three classes of individuals are easily recognisable—(1), a class of small stems with restricted crowns and below the average height of the crop; (2), a middle class with freely developed crowns and of the same height as the crop; and (3), a class of thicker stems with crowns rising above the general mass of the crop. To these classes may be added two others, *viz.*, that of suppressed individuals and that of old standards or trees of much greater age than the rest of the crop, and conspicuous by their relatively great size. These several classes are generally at once recognisable from the figures of the enumeration survey.
- III.—THAT OF EQUAL GROUPS.—If natural size-classes are not distinguishable by their relative thickness of stem, then it is advisable to form classes containing approximately the same number of stems. In this method the range of girth included will obviously differ from class to class, and the method is therefore to this extent the very opposite of I.

The number of sample trees to measure in each girth-class will depend (i), on the relative proportion to the entire crop which the class represents either in respect of number of stems or of cubical contents; (ii), on the uniformity of the component trees in

- respect of height and shape, *i.e.*, the case of greater or less difficulty in selecting correct representatives of the class in question, and (iii), on the possibility of errors due to an insufficient number selected in one or more classes being compensated by excess or deficiency of results obtained for the other classes. Obviously the possibility of such compensation exists only if each sample stem represents approximately an equal fraction of the total contents of the crop.

As a rule, the number of sample trees measured in any girth-class is determined by the proportion either (a) of the number of stems, or (b) of the aggregate basal sectional areas comprised in that class. The adoption of the latter of these two bases of calculation is always more likely to give correct results.

The grouping of the trees into height-classes must take place at the time of the enumeration survey, and be a part of that operation; their separation into girth-classes may be effected after the survey with the help of the figures which it furnishes.

To illustrate what has been said in this section we append below a specimen of a survey by girth-classes.

Forest Kanjatra Sample Plot (a) 264' x 165'. Age 135 years.
Compartment 97. Area 1 acre. Density of stock 0.9.

Girth in inches at breast-height.	Species, Spruce.				Number of stems.	Basal area in square feet.	SAMPLE STEMS.						Remarks.
							Girth.	Basal area.	Quantity of wood.	Height.	Form-factor.	Age.	
							In.	Sq. ft.	C. ft.	Ft.		Yrs.	
30	III				6	2.344							
33	III				8	3.781							
36	III	I		I.	11	6.187	39	.6601	27.33	92	.45	135	
39	III	III			14	9.242			branches		.957=31%		
42	III	III			17	13.016							

Girth in inches at breast-height.	Species, Spruce.				Number of stems.	Basal area, in square feet.	SAMPLE STEMS.						Remarks.
							Girth.	Basal area.	Quantity of wood.	Height.	Form-factor.	Age.	
45	II	II			II	16	14.062						
48	II	II				19	19.000	51	1.1289	35.88	111	43	133
51	II	II	III			24	27.094	54	1.2656	59.00	111	42	136
54	II	II				16	20.250		2.3945	112.88			
57	II	II				16	22.562	branches 4.52=4°.					
60	II	III				14	21.875						
63	II	II			III	17	29.285	69	2.0664	95.05	115	40	134
66	II					10	18.906	72	2.2500	101.79	116	39	135
69	II	I				11	22.730						
72	II					7	15.750		4.3164	196.84			
75	II					7	17.090	branches 8.46=4.3°.					
78	III					3	7.922						
81	III					3	8.543						
Girth Class						56	34.570						
" "						105	124.843						
" "						58	120.226						
Total						219	279.639						

Calculation of Quantity of Wood.

$$C_1 = 27.33 \times \frac{34.570}{6} = 1,431 \text{ c. ft.}$$

$$C_2 = 112.88 \times \frac{124.843}{2.3945} = 5,885 \text{ ,,}$$

$$C_3 = 196.84 \times \frac{120.226}{4.3164} = 5,482 \text{ ,,}$$

12,798 ,, = wood of stems.

Add 4 % 552 ,, = ,, ,, branches.

Total Wood 13,350 ,,

Calculation of Average Stems.

$$a_1 = \frac{34.570}{56} = 0.6171 \text{ sq. ft. and } g_1 = 38 \text{ in.}$$

$$a_2 = \frac{124.843}{105} = 1.1890 \text{ ,, ,, } g_2 = 52 \text{ ,,}$$

$$a_3 = \frac{120.226}{158} = 0.7615 \text{ ,, ,, } g_3 = 69 \text{ ,,}$$

7. *Survey by Girth-gradations. Methods of Draudt, Ulrich, and Hartig.*

Whenever it is impossible to determine accurately the average tree even for separate girth-classes, it is necessary to adopt as the basis of survey girth-gradations (*see* page 13, I A a γ), which obviously require the measurement of a larger number of sample stems than the method just described, the number for each gradation being proportional to the total number of stems comprised in that gradation.

Several methods of survey by girth-gradations have been devised, but we will describe here only those of Draudt, Ulrich, and Robert Hartig:—

DRAUDT'S METHOD.

In this method a certain proportion, say the x -th part, of all the

trees in each gradation, and, therefore, also in the whole crop, are measured as sample trees, the number of such sample trees being therefore

$$= \frac{n}{z} = \text{say } \zeta.$$

Now as the sample trees represent the z -th portion of the whole crop, not only in number but also in respect of contents and basal area, we have

$$A = a \cdot z \text{ and } C = c z = c \frac{n}{\zeta} = c \frac{A}{a}.$$

As the z -th part of the number of trees composing a girth gradation may not be a whole number, and we cannot measure a fraction of a tree, it is best, in calculating the cubical contents of all the trees in a gradation, to use the last of these equalities, which enables us to measure up whole stems only, and also renders it unnecessary for the sample stems to be exact average stems for the gradation in question.

In practice the procedure is as follows:—

An enumeration survey is effected in classes having a sufficiently wide range of girth (say 6 inches). This being done, the figure z is determined, and the number of sample stems to be measured for each gradation is then the nearest integer in the expression $\frac{n}{z}$. But if $\frac{n}{z}$ is a very small fraction, as many gradations are lumped up together as will give one sample tree; and when this is done, the basal area of the sample tree is determined in the same way as when several girth-classes of the enumeration survey are lumped up together to form a new girth-gradation (see the figures at the bottom of the example at end of the preceding section). The girths and basal areas of all the sample stems are then carefully registered, and their cubical contents accurately measured and expressed, either in one lump figure or in separate figures giving the respective quantities of timber, fire-wood, etc. Lastly, the contents of all the trees in each gradation are calculated

by the formula $C = c \frac{A}{a}$. If the trees falling under one and the same girth-gradation are of very different heights, this fact must be borne in mind in selecting the sample trees, or the girth-gradation may be divided into sub-classes according to height and each sub-class treated in the way described.

The great advantage which Draudt's method offers is, that all the sample stems for the whole crop may be measured up together and their contents determined, not only in one lump figure, but also according to the different classes of produce they yield, thereby enabling us to estimate by means of a few easy multiplications the contents of the entire crop.

URICH'S METHOD.

We have seen that in Draudt's method fractions in the quotient of $\left(\frac{n}{z}\right)$ are got rid of by taking the nearest whole number, but where the quotient is much less than unity, several quotients are added together, and the result worked out for a group of girth-gradations. This procedure is obviously not quite logical, and hence Ulrich has modified it so as to secure greater consistency. He adopts the latter principle throughout, and his system is accordingly always to carry over all fractions to the next class. The sample trees are hence seldom required to represent a separate girth-gradation, but nearly always a group composed of the whole or portions of two or more such gradations. The girth of the sample trees for each group is accordingly determined by the proportion of the respective numbers of the several gradations composing the group. When the formula $C = c \frac{A}{a}$ is employed, it is not so necessary that the sample tree should be representative of the group in respect of volume as in respect of height and form-factor.

The advantages of Ulrich's method are the same as those of Draudt's.

In its valuation surveys the Commission for Forest Research in Germany adopts five girth groups, and fells from two to three sample stems for each group. This is a combination of Ulrich's principle with the method of girth-classes.

HARTIG'S METHOD.

In this method the groups are so formed that the component trees aggregate equal basal areas.

The procedure is as follows:—

First decide what number of sample trees (ζ) or of groups of trees (G) we require, and then determine the aggregate basal area to be included in each group (this area = $\frac{A}{\zeta}$ or $\frac{A}{G}$). Now form the groups, beginning with the smallest class of trees. Next the girths of the several sample trees are either fixed approximately by inspection, or rigorously determined by means of the formula $a = \frac{A}{n}$. Each sample stem is then measured by itself, and the contents of the corresponding group ascertained with the help of the formula $C = c \frac{A}{a}$. Or the contents of each sample tree may be considered as the contents of an imaginary cylinder of the same base as the tree, and the corresponding height of the cylinder obtained from the formula $h = \frac{c}{a^2}$, the total contents of the crop being the product of the total basal area of the crop multiplied by the mean of all the cylindrical heights thus obtained.

In this method the larger stems obviously compose, number for number, more groups than the smaller ones, and the sample trees, although of course samples of the corresponding group, are not samples of the crop considered as a whole. The contents or yield in different classes of produce of the sample trees cannot hence be worked up together in one place, and the main advantage afforded by Draudt's method is thereby lost. Comparing the two methods, Hartig's may be employed when as accurate as possible an estimate of the contents of the crop is required with the help of only a few sample trees, whereas Draudt's should be adopted when it is possible to fell a larger number of sample trees and an estimate of the yield in different classes of produce is required.

EXAMPLE OF THE THREE METHODS.

To render the preceding explanations clear, we proceed to show below, by means of a comparative parallel statement, how to use the three methods of valuation just described. We take the case of a 4.7-acre sample plot of beech.

Distribution of the Sample Stems.													
Result of Enumeration Survey.			Drandt's Method.		Ulrich's Method.				Hartig's Method.				
			$\zeta=10;$ $z=75$		$\zeta=10; z=75$				$A=863.763; \zeta=10; \frac{A}{10}=86.3763$				
Girth in inches at breast-height.	Number of trees.	Basal area in square feet.	Number	Girth.	Girth.	Number of trees.	Running number	Average girth.	Girth.	Number of trees.	Basal area.	Running number	Average girth.
			of the sample stems.				of the sample stems.					of the sample stems.	
					24	50			24	50	12.500		
					30	25			30	114	44.530		
						75	1	27	36	9	5.062		
24	50	12.500	1	24						173	62.092	1	30
					30	75	2	30	36	110	61.875	2	36
30	114	44.530	1	30	30	14			36	39	21.937		
					36	61			42	52	30.812		
						75	3	36	42	91	52.749	3	42
36	158	88.875	2	36	36	75	4	36	42	81	62.016	4	42
					36	22			42	23	17.609		
42	156	119.487	2	42	42	53			48	44	44.000		
						75	5	39		67	61.609	5	42
48	128	128.000	2	48	42	75	6	42	48	62	62.000	6	48
					42	28			54	31	39.234		
54	66	83.531	1	54	48	47				53	61.234	7	51
						75	7	45					
60	42	65.625			48	75	8	48	54	35	44.297		
									60	11	17.187		
66	19	35.922			48	6				46	61.484	8	54
					54	66							
					60	3	9	54	60	31	48.437		
			1	66		75			66	7	13.234		
										38	61.671	9	60
72	12	27.000			60	39			66	12	22.687		
					66	19			72	12	27.000		
78	5	13.203			72	12			78	5	13.203		
					78	5							
						75	10	66					
750	618.623		10						29	62.890		10	72

In the preceding example, in applying Draudt's method, the trees respectively of the four highest girth-classes being separately very much less than Z (75), are lumped up together for the purpose of the valuation.

To complete illustration of Ulrich's method, let us suppose that we have selected and felled ten sample trees of the respective average girth, and that they furnish the following figures:—

Total basal area of the 10 trees	11.62 sq. ft.
Yield in timber	98.53 solid c. ft.
„ „ fire-wood	856.40 stacked c. ft.
„ „ faggot-wood	84.70 „ „

Then $\frac{A}{a} = \frac{617.223}{11.62} = 53.1$, and the contents of the whole crop are—

Timber	= 98.53 × 53.1 = 5,232 solid c. ft.
Fire-wood	= 856.40 × 53.1 = 45,475 stacked c. ft.
Faggot-wood	= 84.7 × 53.1 = 4,498 „ „

The completion of the valuation by Hartig's method is effected in the following tabular statement:—

THE SAMPLE STEMS.						Contents of each Group.			$\frac{A}{a}$	
Running number.	Girth.	Basal area.	Contents.		Total.	Height of cylinder. $hf = \frac{c}{a}$	$C = c \frac{A}{a}$			
			Large wood.	Fag-got wood.			Large wood.	Fag-got wood.		Total.
in.	sq. ft.	Cubic feet solid.		ft.	Cubic feet solid.					
1	30	.3906	17.2	3.4	20.6	52.7	2,734	540	3,274	62.092 + .3906 = 158.96
2	36	.5625	27.5	5.5	33.0	58.7	3,025	605	3,630	61.875 + .5625 = 110.00
3	42	.7656	40.0	8.0	48.0	62.7	3,226	645	3,871	61.749 + .7656 = 80.65
4	42	.7656	40.0	8.0	48.0	62.7	3,240	648	3,888	62.016 + .7656 = 81.00
5	46	.9184	53.2	8.4	61.6	67.1	3,569	563	4,132	61.609 + .9184 = 67.08
6	48	1.0000	54.7	8.5	63.2	63.2	3,391	527	3,918	62.000 + 1.0000 = 62.00
7	51	1.1289	62.8	8.8	71.6	68.4	3,406	477	3,883	61.284 + 1.1289 = 54.24
8	54	1.2656	71.0	9.4	80.4	63.5	3,449	457	3,906	61.484 + 1.2656 = 48.58
9	60	1.5625	88.0	10.0	98.0	62.7	3,473	395	3,868	61.671 + 1.5625 = 39.47
10	70	2.1267	145.0	14.4	159.4	74.9	4,288	426	4,714	62.890 + 2.1267 = 29.57
Total						631.6	33,801	5,283	39,084	

Or we may use the formula $C = A HF$; whence total contents = $617.223 \times \frac{631.6}{10} = 38,984$ cubic feet.

8. Number, selection and measurement of the sample trees.

The number of sample trees to be measured will depend on the method of survey adopted, and on the size and the degree of uniformity of the crop. The method of survey which requires the smallest number is that of the average tree, 2 or 3 stems sufficing if the crop is regular. In survey by girth-and-height classes from 6 to 15 trees must be measured. Draudt's method requires from 10 to 15.

Since special circumstances, independent of the method of survey, often limit the number of trees that may be felled, the choice of the method of survey must, in such cases, be regulated by the number of trees which it is permissible to fell. It must, however, be borne in mind that the greatest accuracy in measuring the sample trees can never compensate for the smallness of their number. Averages derived from the measurement of a large number of trees will, even if the measurements have been made less carefully, be more trustworthy than those obtained with the help of a smaller number of trees. There is less error in *estimating* the contents of a large number of *standing* trees with the aid of Volume Tables, or by means of the *richt*-height, than in measuring up an insufficient number of felled trees *in the most accurate manner possible*.

The care exercised in selecting the sample stems must be in proportion to the smallness of their number. They must be as nearly as possible correct representatives of their class in respect of height, form and branching, and all forked and otherwise abnormal trees should be avoided. Moreover, the boles should be perfectly regular at the places where the girth has to be measured. When a diameter calliper is used, at least two diameters should be taken at each place to obtain a correct average. When the number of sample trees to be felled is large, they should be situated at different points of the entire crop. The sample trees should always be chosen immediately after the enumeration survey has been completed, and by the same person who has conducted this survey, and who has therefore a correct and vivid general impression of the character of the crop and the component trees.

The cubing of the sample trees should be effected as accurately as possible by the rules already laid down for the measurement of felled trees.

9. Valuation survey by means of the right-height.

The lower girths of all the trees of the crop being known from the enumeration survey, the total basal area, A , is calculated therefrom. Next the *right-height* of a sufficient number of sample stems should be observed, and the average of all these figures assumed as the *right-height* H_r of the whole crop. The contents of the crop are then obtained from the formula

$$C = \frac{1}{2} AH_r + Ah_o.$$

The contents of the branches must be added as a percentage, which must be taken from tables, or deduced from the results of previous surveys of similar crops.

The crop may of course be divided into girth-and-height classes, and the average *right-height* determined for each class separately.

10. With the aid of tables of form-factors or volumes.

The girth of all the trees of the crop are already known from the enumeration survey. The heights of a sufficiently large number of trees must be measured, and the average heights which correspond to different girths determined therefrom. The following is an example, exhibiting a convenient mode of arranging and manipulating the various figures:—

Girth in inches	24	30	36	42	48	54	60	66	72	78
	Height in feet.									
Species—Beech	82	98	104	111	111	115	114	115	120	117
	...	96	107	114	112	112	115	112	117	...
	...	...	102	111	...	114	...	...	116	...
Total height	82	194	313	336	223	341	229	227	353	117
Average height	82	97	104	112	112	114	114	114	118	117
Corrected height	82	97	104	110	113	114	114	114	116	117

The calculation is completed thus (in the field-book itself of the enumeration survey)—

Compartment 11.

Girth in inches.	Species—Beech.	Number of trees.	Average height in feet.	CONTENTS.		Remarks.
				Per tree.	Total.	
				Solid cubic feet.		
24	Here will be recorded the figures of the enumeration survey.	50	82	13.9	695	
30		114	97	25.8	2,937	
36		158	104	41.2	6,510	
42		156	110	60.0	9,360	
48		128	113	82.1	10,509	
54		66	114	107.0	7,062	
60		42	114	133.0	5,586	
66		19	114	163.0	3,097	
72		12	116	198.0	2,376	
78		5	117	237.0	1,185	
		750	...	...	49,317	

The "contents per tree" are obtained from the tables of form-factors or volumes, as the case may be.

11. Valuation survey by ocular estimate.

Two modes of procedure may be adopted—

I.—The contents of each tree of the crop may be estimated, the contents of the entire crop being then obtained by a mere sum of simple addition. Such a procedure, however, takes as much time as a complete enumeration survey based on the actual measurement of the girths of the trees, and once the girths have been measured and recorded, there is very little extra trouble in measuring the heights of a few trees and obtaining the contents of the crop by the much more trustworthy method of valuation by the *richt*-height, or with the aid of tables of form-factors or of volumes.

II.—The contents of the whole crop may be estimated *en bloc*. An intelligent forester who has had long local experience in the clean-felling of coupes can often give a fairly accurate estimate of the quantity of produce standing per acre, but the best man is nevertheless liable to make an error of as much as 50 per cent.

12. *Valuation survey by means of tables of yield.*

In this method the surveyor must determine three essential points:—

- (a) The quality of the soil and locality.
- (b) The density of the crop.
- (c) The age of the crop.

The older tables of yield drawn up in Germany omitted the first point. In the tables recently issued, for each forest or class of forest a certain convenient number of classes of soil and locality are established according to the height attained by the trees in each. Hence, for any particular crop in question, we have only to ascertain the average height of the trees, in order to know at once the quality of the soil and locality.

The age of the crop will be known from its past history, if it has one going back far enough; or it must be ascertained by ring-countings, if some constant relation exists between the number of concentric rings and the number of years in which this number of rings is produced. Otherwise there is no means of obtaining it with any degree of accuracy.

The density of a crop is an extremely difficult thing to estimate with sufficient accuracy. It can, of course, be determined by measuring the girths of all the trees and thus obtaining their aggregate basal area, but this means almost as much work as far more trustworthy methods of valuation survey with the aid of sample trees.

13. *Choice of the method of valuation survey.*

From what has already been said in describing the various methods of valuation survey, it is clear that this choice in any given case depends—

- (a) on the required degree of accuracy;
- (b) on the nature of the crop, and
- (c) on the number of individuals that may be felled as sample trees.

If the money-value of a crop is sought, as would be required if the crop is to be sold or the forest expropriated, or if the owner wished to obtain accurate statistical data regarding his property, Ulrich's method should be employed. For the purposes of a work-

ing plan a less exact method is admissible, particularly as regards the younger crops, which must be surveyed over again when the plan is revised. Hence for such crops a complete survey is seldom necessary, and in the sample plots the method of *richt*-height and those based on tables of form-factors or of volumes or of yield may be adopted. But where a certain degree of accuracy is required, the method of survey by the average tree may be employed in regular crops, a higher degree of accuracy being secured by the establishment of girth-classes and the highest by Ulrich's method, which is moreover the only one to adopt when it is required to estimate the yield in the various marketable classes of converted wood.

The establishment of height-classes gives a great deal of trouble and extra work. It should be avoided whenever possible, that is to say, as often as the heights of the trees composing the crop do not exhibit any marked irregularity.

Chapter V.

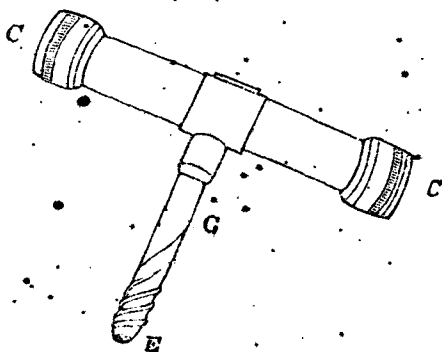
On the determination of the ages of trees and crops.

The determination of the age of trees and of crops is a problem which often presents insurmountable difficulties to the Indian forester, since not only are the ring markings indistinct and sometimes indistinguishable, but so many of our species form more than one concentric ring of wood each year, and there is nothing to prove that in their case the number of rings is one and the same for each year. The following remarks hence apply only to species which invariably form a single distinct concentric ring of wood each year.

1. *Determination of the age of standing trees.*

The ages of individuals of most of our conifers can, as long as they are branched down to the ground, be accurately determined by counting the number of annual shoots. The age of other trees can generally be told to within 10-20 years by a forester possessed of large local experience. But the most certain way of ascertaining the exact age of a tree is to use Pressler's borer, which should be long enough to reach, or all but reach, the centre of the trunk.

This instrument (*see figure*) is a gimlet, consisting of a tube (G) with a very sharp-cutting edge (E).



To render the instrument easily portable, the gimlet-portion G can be taken off and put into the cylinder CC, which is hollow, and the caps of which unscrew off.

As the tube is forced into the trunk of a tree, a cylinder of wood is cut out by the tube. On withdrawing the gimlet, the cylinder of wood can be easily pushed out of the tube and the ring-markings on it counted. When the borer does not quite reach the centre of the tree, the age of the remaining portion of the trunk can be estimated with sufficient accuracy.

If the conditions of the forest have not materially altered since the appearance of the trees experimented upon, the ring-countings will give also the age of individuals of any girth-class smaller than the class to which those trees belong.

2. *Determination of the age of felled trees.*

It is scarcely necessary to say that, under the assumption made at the beginning of this chapter, the required age is accurately determined by counting the number of concentric rings on the section of the stool or trunk. The remark made in the last paragraph of the preceding article holds good here also.

3. *Determination of the age of entire crops.*

If the crop is regular, its age is practically the age of the middle class of stems composing it, and it will hence suffice to determine the age of one of those stems, or, to be on the safe side, of a few of them.

If the crop is irregular, the problem becomes more or less complicated. Several stems of the different girth-classes present must be examined, and when the respective ages of the several classes have been determined, the question to be solved is how to obtain the mean age of the crop from them. To take the mere arithmetical mean of the several ages without reference to the respective areas occupied by them, or to the quantity of material each represents, would evidently be wrong. We now proceed to investigate different methods for obtaining the true mean age which may be defined as that age at which a crop of uniform age would, under the same conditions of soil, locality and species, have produced the same volume of material as the actual crop contains.

Let $v_1, v_2, v_3 \dots$ = respectively the volumes of the several classes aged, respectively, $y_1, y_2, y_3 \dots$ years, and Y = the required mean age = the age of the imaginary equivalent crop. By hypothesis the mean annual increment of both crops is one and the same; let this increment = I . Then—

$$IY = v_1 + v_2 + v_3 \dots$$

$$\text{and } I = \frac{v_1}{y_1} + \frac{v_2}{y_2} + \frac{v_3}{y_3} \dots;$$

$$\text{Hence } \left(\frac{v_1}{y_1} + \frac{v_2}{y_2} + \frac{v_3}{y_3} \dots \right) Y = v_1 + v_2 + v_3 \dots$$

$$\text{and } Y = \frac{v_1 + v_2 + v_3 \dots}{\frac{v_1}{y_1} + \frac{v_2}{y_2} + \frac{v_3}{y_3} \dots} \dots \dots \text{Formula (v).}$$

Expressed in words, the preceding formula would run thus:—
To obtain the mean age of a crop composed of trees of diverse ages, divide the total volume of material on the ground by the sum of the mean annual increments of the several age-classes.

Since the age of trees is, at least approximately, a function of their girths, the girth-classes may be considered as coincident with age-classes, and the words "girth-classes" may be substituted for "age-classes" in the above rule.

Let us now investigate another formula for the case in which the respective areas $\alpha_1, \alpha_2, \alpha_3 \dots$ occupied by the diameter-classes are known. If $i_1, i_2, i_3 \dots$ = respectively the mean annual increment per unit of surface in the different areas $\alpha_1, \alpha_2, \alpha_3 \dots$, then we have

$$v_1 = \alpha_1 i_1 y_1; v_2 = \alpha_2 i_2 y_2; v_3 = \alpha_3 i_3 y_3; \dots;$$

$$\text{and } \frac{v_1}{y_1} = \alpha_1 i_1; \frac{v_2}{y_2} = \alpha_2 i_2; \frac{v_3}{y_3} = \alpha_3 i_3; \dots$$

Substituting these values of v and $\frac{y}{y}$ in formula (v), we have

$$Y = \frac{\alpha_1 y_1 i_1 + \alpha_2 i_2 y_2 + \alpha_3 i_3 y_3 \dots}{\alpha_1 i_1 + \alpha_2 i_2 + \alpha_3 i_3 \dots}$$

If in the above formula, $i_1 = i_2 = i_3 = \dots$, we have

$$Y = \frac{\alpha_1 y_1 + \alpha_2 y_2 + \alpha_3 y_3 \dots}{\alpha_1 + \alpha_2 + \alpha_3 \dots} \dots \text{Formula (vi).}$$

The employment of this formula presupposes a knowledge of the respective areas occupied by the different age-classes. It is, therefore, not adapted for the calculation of the mean age of a crop composed of trees of various intermixed ages, but its special use is for the determination of the mean age of several crops considered together, or even of an entire working circle, and it is generally employed for this purpose. It gives the same result as Formula (v) when Y is approximately the age at which the highest mean annual increment occurs.

It now remains to investigate a formula for finding out the mean age of the crop when we know only the numbers $n_1, n_2, n_3 \dots$ of trees included respectively in the several classes whose ages are $y_1, y_2, y_3 \dots$. By the ordinary rule of arithmetic for obtaining averages, we have the mean age of the crop

$$Y = \frac{n_1 y_1 + n_2 y_2 + n_3 y_3 \dots}{n_1 + n_2 + n_3 \dots} \dots \text{Formula (vii).}$$

If this formula is to yield the same result as Formula (v), it is necessary that the mean annual increment of all the diameter-classes should be one and the same. For let $\chi_1, \chi_2, \chi_3 \dots$ = the mean annual increments of the average trees of the several classes then

$\bar{v}_1 = \chi_1 y_1 n_1; v_2 = \chi_2 y_2 n_2; v_3 = \chi_3 y_3 n_3; \dots$
and by formula (v)

$$Y = \frac{\chi_1 y_1 n_1 + \chi_2 y_2 n_2 + \chi_3 y_3 n_3 \dots}{\chi_1 n_1 + \chi_2 n_2 + \chi_3 n_3 \dots}$$

Hence, in order that formula (vii) should at the same time be true, we must have

$$\chi_1 = \chi_2 = \chi_3 \dots$$

For formula (vii) to give the same result as formula (vi), it

is necessary that the number of trees per unit of area should be one and the same for all the age-classes. For let $v_1, n_2, v_3, \dots$ be respectively these numbers for the several classes, then

$$n_1 = \alpha_1 v_1; n_2 = \alpha_2 v_2; n_3 = \alpha_3 v_3; \dots$$

and by formula (vii)

$$Y = \frac{\alpha_1 v_1 y_1 + \alpha_2 v_2 y_2 + \alpha_3 v_3 y_3 + \dots}{\alpha_1 v_1 + \alpha_2 v_2 + \alpha_3 v_3 + \dots};$$

by formula (vi)

$$Y \text{ also } = \frac{\alpha_1 y_1 + \alpha_2 y_2 + \alpha_3 y_3 + \dots}{\alpha_1 + \alpha_2 + \alpha_3 + \dots};$$

and we must hence have

$$v_1 = v_2 = v_3 = \dots$$

It has now been shown that formula (vii) holds good only on condition (a) that the mean annual increment is one and the same for all the girth classes, and (b) that the number of trees per acre is one and the same at all ages, assumptions that are incompatible with actual facts. Hence the employment of this formula should be avoided.

If in formula (vii) we assume that $n_1 = n_2 = n_3 \dots = n$; that is to say, that the number of stems in each age-class is the same, we have

$$Y = \frac{y_1 + y_2 + y_3 + \dots}{n}$$

= the arithmetical mean of the ages of the sample trees. Now, in Ulrich's method of valuation survey each sample tree corresponds to one and the same number of trees in the crop. Hence if, in working according to that method, we deduce the mean age of the crop by taking the mean of the ages of the sample trees, we obtain the same result as if we had adopted formula (vii), which has just been shown to be incorrect.

Nevertheless, as by far the easiest way of determining the mean age of a crop is to take the simple arithmetical mean of the ages of the sample trees, let us examine under what conditions such a procedure would give correct results.

Let us then suppose that in this special case the mean age of the crop is equal to the arithmetical mean of the ages of the sample trees. Hence

$$\frac{y_1 + y_2 + y_3 + \dots + y_n}{n} = Y = \frac{v_1 + v_2 + v_3 + \dots + v_n}{\frac{v_1}{y_1} + \frac{v_2}{y_2} + \frac{v_3}{y_3} + \dots + \frac{v_n}{y_n}} \quad [\text{by Formula (v)}]$$

Multiply both the numerator and denominator of the first side of the equation by such a number z that the numerators of both sides may be equal. Then the denominators will also be equal.

Hence $z y_1 + z y_2 + z y_3 \dots z y_n = v_1 + v_2 + v_3 \dots + v_n$,

and $z + z + z$ up to n terms $= \frac{v_1}{y_1} + \frac{v_2}{y_2} + \frac{v_3}{y_3} \dots + \frac{v_n}{y_n}$.

These two equalities are possible only on the condition that the first, second, third ... terms of one side are equal respectively to the first, second, third ... terms of the other side, that is to say,

$$z y_1 = v_1 ; z y_2 = v_2 ; z y_3 = v_3 ; \dots z y_n = v_n ;$$

$$\text{and } z = \frac{v_1}{y_1} = \frac{v_2}{y_2} = \frac{v_3}{y_3} \dots = \frac{v_n}{y_n} ;$$

But volume (v) = basal area $\times$ height $\times$ form-factor = ahf ,

$$\therefore \frac{a_1 h_1 f_1}{y_1} = \frac{a_2 h_2 f_2}{y_2} = \frac{a_3 h_3 f_3}{y_3} \dots$$

Now we may assume that in one and the same crop the mean annual increment of height $\times$ form-factor (*viz.*, $\frac{hf}{y}$) is approximately equal, that is that

$$\frac{h_1 f_1}{y_1} = \frac{h_2 f_2}{y_2} = \frac{h_3 f_3}{y_3} = \dots$$

Hence

$$a_1 = a_2 = a_3 \dots$$

These conditions are fulfilled by the distribution of the sample trees in Hartig's method of valuation, so that in that method the mean of the ages of the sample trees gives the mean age of the crop.

For the employment of formula (v) a survey by girth-classes is necessary in order to be able to determine the volume of material contained in the several classes. This is not possible by Ulrich's method.

It may sometimes occur, when only a few sample trees are felled, that the smaller are found to be older than others of larger girth. In such a case we may still take the arithmetical mean of the ages on the not improbable assumption that there is a wide difference of ages between the several individuals of each of the girth-classes, and that for one sample tree that gives too high a figure for the mean age of its class, there is another which gives the same amount of compensating error on the other side—errors of excess and defect thus cancelling each other. The smaller the

difference between the ages of the oldest and youngest trees in one and the same girth-class is, the more approximate to the true mean age of the crop will be the arithmetical mean of the ages of the sample trees. And the result will be all the nearer, when the number of sample trees taken is, is large and the more closely the system of forming the stem-classes approaches that of Hartig's method.

Chapter VI.

Determination of the rate of increase of individual trees and of canopied masses of trees.

Single trees increase in height, girth, basal area and volume. Similarly, crops of trees increase in height, aggregate basal area and volume.

The *current annual increment* of a tree or crop is the amount by which it has increased during the past year.

Periodic increment is the amount of increase gained during a period of several years.

The *total increment* of a tree or crop is its actual volume at any given time (the sum of all the annual increments up to the given time).

The expression *mean increment*, when used without any other qualifying word, may refer to merely a period, or to the entire age of the tree or crop, or to the age when the tree or crop becomes exploitable.

In determining the increment for a single year, it is customary to assume for it the figure of the mean increment for a short period of years, because the increment for a single year is not only composed of factors too small to be accurately measured, but is subject to disproportionably large fluctuations from year to year.

For many purposes the increment is conveniently expressed as a percentage.

1. Increment of individual trees.

A. Rate of increase in height.

The rate at which the height has increased can be determined at once in the case of most conifers, since the length of each annual shoot is apparent owing to their peculiar mode of branching.

In the case of broad-leaved trees, the stem must be cut across at

the top. If the section shows n annual rings, the portion cut off is n years old, and the point must be found at which there are exactly n such rings, the number immediately below being $n + 1$.

When the increment for every stage of the existence of the tree is sought, the stem must be divided into equal sections, say of 5 feet length. The number of annual rings counted on the upper surface of each section will give the number of years' growth above it, and the difference between the age of the whole tree and this number will give the number of years which the tree has taken to attain the height at which the rings have been counted. The preceding mode of procedure must be adopted even for conifers when the lower branches have fallen off.

It is evident that if the number of concentric rings does not correspond in any way with the age of the tree, the determination of the height increment, except for recent years the shoots corresponding to which are apparent at the top of the stem, is impossible.

B. Rate of increase in diameter and basal area.

As it is impossible, or at least very difficult, to ascertain the girth-increment by direct measurement, it must be deduced from the diameter increment by multiplication by $\pi = 3.14$. To obtain the diameter increment, measurements are generally made at the usual height of $4\frac{1}{2}$ foot, or breast-height, but they may be made instead at the middle of the tree, or, if great accuracy is required, at several places.

In the case of trees forming one or a regular number of rings each year, the diameter increment of a given year or period of years is found by measuring the thickness of the layer of wood put on during that interval. The thickness of this layer must be measured on several pair of radii, each pair belonging to one and the same diameter. Twice the mean of the several measurements will give the increment sought. A single measurement is justifiable only when both the shape of the stem and crown and the branching are extremely regular. If the tree cannot be felled, Pressler's borer should be used. The increment of the sectional area at any height will be given by the formula

$$\frac{\pi}{4} (D^2 - d^2) = 0.7854 (D + d) (D - d)$$

where d = diameter at the beginning of the year or period, and D = diameter at the end of the same.

As regards trees, the different concentric woody layers composing which are not distinguishable, or, even if distinguishable, are not the same in number for each year, the procedure just described is not applicable. In their case the only plan to follow is to measure trees of known ages and growing under identical conditions of soil, locality and leaf-canopy, and deduce the required increment or increments by comparing the various figures thus obtained. Where trees of different known ages are not obtainable, there is no alternative but to select one or more plots representing the average characters of the entire forest in respect of soil, locality, composition and density, and containing between them individuals of all the age-classes. These sample plots should be properly thinned from time to time, so that none but trees growing without any unnecessary check may come under observation. In order to secure this object more effectually, no suppressed or overtopped trees should be measured, nor even those that have their tops exposed to the sky if their crowns have a restricted development owing to lateral pressure from their neighbours. Subject to these exceptions, the girths of all the trees should be taken at regular intervals of one to five years, according to the rapidity of growth of the trees. Unless the trees increase in girth very rapidly, the interval should not be less than two years, for not only is the increment of a single year a small quantity difficult to appreciate; but various disturbing causes, of which the splitting of the bark and its falling off in scales and the varying amount of moisture in it, are the chief, combine to mask or exaggerate it, as the case may be. The measurements should be taken each time along the same circumference; and in order to secure this each stem should be encircled with a steady line of white paint about half an inch wide. The most lasting paint is zinc white. According to the nature of the bark, the ring of paint must be renewed at longer or shorter periods. The entire ring should lie in the plane at right angles to the axis of the bole at the height at which it is painted. The rings should be painted at 4½ feet from the ground, but if there is some marked irregularity of growth at this height, two rings may be painted respectively above and below this height at an equal distance from it in accordance with the principle laid down in rule (f) on page

4. In measuring the girth, the tape should be laid along either the lower or the upper edge of each ring, never along both indifferently. Experience has shown that it is most convenient to measure along the lower edge. The tree should be numbered consecutively for recognition, and the numbers should be painted on the bark close to the ring. Labels, of whatsoever pattern, should never be used, as they ultimately drop off and get lost, and the trees are then no longer recognisable. A careful register of all the measurements taken should be kept in something like the following form :—

Trees.		Girth in inches on 1st January						REMARKS.
Species.	Running number.	1890.	1898.	1896.	1899.	1902.	1905.	

In the last column will be entered all pertinent remarks, such as "Released from lateral pressure in thinnings of 1890;" "Over-topped, no longer measured;" "Found dead in 1896," and so on. If trees of all sizes are represented in the sample plots, a series of from 5 to 15 consecutive measurements, according to the length of the interval at which the measurements are taken (the shorter the interval, the larger the number of measurements required), will furnish complete data for computing the increments for all periods and at various ages. For the jardinage type of forests, each sample plot should contain individuals of various widely-differing ages; in all other cases, each sample plot should contain only trees belonging to a single age-class, or, if there is a double storey of growth, to two age-classes.

C. Rate of increase of volume:

The increment put on during a given number of years x may be obtained in several different ways as follows :—

I. BY THE CUBING OF THE STEM IN SECTIONS.—The stem being cut up into sections from 6 to 12 feet long, the actual

and former diameters (D and d) are measured on each section exclusive of the bark. The actual and former contents of the stem can thus be calculated, and their difference is the increment sought. This method is practicable only when the annual concentric rings are distinguishable.

- II. BY MEASURING THE ACTUAL AND FORMER DIAMETERS AT HALF THE HEIGHT OF THE TREE n YEARS AGO.—The length of stem added on during the past n years is removed, and the remaining log (whose length $= h$) is then cut across through the middle. The diameters D and d being now measured, the increment sought

$$= I_n = \frac{\pi}{4} h (D^2 - d^2).$$

- III. BY MEANS OF FORM FACTORS.—In this case it is assumed that during short periods the form factor does not vary in any appreciable manner. If D , H , and V denote respectively the actual diameter, height and volume, and d , h , and v the corresponding figures n years ago, then

$$I_n = V - v = \frac{\pi}{4} (D^2 H - d^2 h) f.$$

This method is suitable for standing trees, when H , D and d can be determined; h must be estimated as accurately as possible.

- IV. BY MEANS OF THE BASAL AREA AND HEIGHT.—Let d and l denote respectively the diameter and length or height n years ago, and δ and λ the corresponding increments during this interval of years. Then we have

$$V = \frac{\pi}{4} (d + \delta)^2 (l + \lambda) f \text{ and } v = \frac{\pi}{4} d^2 l f.$$

$$\text{Hence } I_n = V - v$$

$$= \frac{\pi}{4} \left\{ (d + \delta)^2 (l + \lambda) - d^2 l \right\} f.$$

$$= \frac{\pi}{4} \left(d^2 l + 2d\delta l + \delta^2 l + d^2 \lambda + 2d\lambda\delta + \delta^2 \lambda - d^2 l \right) f$$

$$= \frac{\pi}{4} \left\{ (2d\delta l + d^2 \lambda) + (\delta^2 l + 2d\lambda\delta + \delta^2 \lambda) \right\} f.$$

Since n is always a small interval of years, the value of the expression in the second bracket is so insignificant that be it may be neglected, and we have, therefore

$$\begin{aligned}
 I_n &= \frac{\pi}{4} f (2d\delta l + d^2\lambda), \\
 &= \frac{\pi}{4} d f (2\delta l + d\lambda) \\
 &= v \left(\frac{2\delta}{d} + \frac{d\lambda}{l} \right), \text{ since } v = \frac{\pi}{4} d^2 l f.
 \end{aligned}$$

In the last formula, when $\lambda = 0$, or something very small, then

$$I_n = v \frac{2\delta}{d}.$$

The mean annual increment of a tree ($\frac{\text{volume}}{\text{age}}$) is often assumed to be the current annual increment. This assumption is justifiable in the case of *crops* that are near the age of exploitability, but should never be made in the case of *individual trees*, the mean annual increment of which, provided they enjoy a fair supply of light on every side, goes on increasing up to a great age.

D. Expression of the increment as a percentage.

To render what follows more easily comprehensible by the student, we will here recapitulate briefly the general principles of interest.

If r = the rate per cent. per annum, then $1.0r = \frac{100 + r}{100} =$

the amount at the end of a year. In the case of simple interest, we have the rule

$$r = 100 \left(\frac{\text{Total interest}}{\text{Principal}} \right) = 100 \times \frac{I}{P}.$$

But in most cases it is necessary to assume compound interest, for which we have the following formulae:—

$$\text{Amount} = A = P(1.0r)^n, \text{ or } 1.0r = \sqrt[n]{\frac{A}{P}}, \text{ or } r = 100 \left(\sqrt[n]{\frac{A}{P}} - 1 \right).$$

For the easy determination of r , Pressler has invented a formula based on the following two assumptions:—(1), that the amount at the middle of the period of years n is equal to $\frac{1}{2}(A + P)$, and (2), that the annual increment is equal to $\frac{1}{n}(A - P)$. He thus gets

$$r : 100 :: \frac{1}{n}(A - P) : \frac{1}{2}(A + P)$$

$$\text{and } r = \frac{A - P}{A + P} \times \frac{200}{n}.$$

This formula is only approximate, and always gives something less than the actual value of r .

We will now apply the preceding principles to the determination of percentages for the increase of (a) the diameter, (b) the sectional area of the stem, and (c) the volume.

(a) *Percentage of increase in diameter.*—According to what precedes, this percentage = $\frac{D-d}{D+d} \times \frac{200}{n}$ for any given section.

The figure thus obtained cannot be applied to any other section, since, as we know, the increment generally increases as we proceed upwards along the stem.

(b) *Percentage of increase of sectional area of stem.*—This percentage

$$\begin{aligned} &= \frac{A-a}{A+a} \times \frac{200}{n} \\ &= \frac{\frac{\pi D^2}{4} - \frac{\pi d^2}{4}}{\frac{\pi D^2}{4} + \frac{\pi d^2}{4}} \times \frac{200}{n} = \frac{D^2 - d^2}{D^2 + d^2} \times \frac{200}{n}. \end{aligned}$$

We may also obtain this percentage (p_a) in terms of the percentage of diametral increment (p_d) thus—

$$\frac{d}{D} = \frac{100}{100 + p_d} \text{ and } \frac{a}{A} = \frac{100}{100 + p_a},$$

$$\text{Hence } \frac{100}{100 + p_a} = \frac{a}{A} = \frac{d^2}{D^2} = \frac{100^2}{100^2 + 200p_d + p_d^2},$$

$$\text{that is to say, } \frac{100}{100 + p_a} = \frac{100}{100 + 2p_d + \frac{p_d^2}{100}}$$

$$\text{and } p_a = 2p_d + \frac{p_d^2}{100}.$$

In the case of rather old trees, the diameter increment of which is very small, $\frac{p_d^2}{100}$ may be neglected, and then we have

$$p_a = 2p_d = \frac{D-d}{D+d} \times \frac{400}{n}.$$

(c) *Percentage of increase in volume.*—In using method II., described under sub-article C. above, it is obvious that, if h is constant, the required percentage

$$= \frac{A-a}{A+a} \times \frac{200}{n} = \frac{D-d}{D+d} \times \frac{400}{n}.$$

According to Pressler this formula gives the percentage of increase in volume not only for the stem alone, but also for the entire tree inclusive of the branches; and experiment has proved this assumption of Pressler's to be very nearly true.

In order to simplify the calculation, Pressler employs the relative diameter $\Delta = \frac{D}{\delta}$, in which D = the actual diameter exclusive of bark, and δ = the increment of the diameter during n years. Now since

$D = \delta\Delta$, and $d = \delta\Delta - \delta = \delta(\Delta - 1)$, we have

$$1.0p \sqrt[n]{(-)\frac{D^2}{d^2}} = \sqrt[n]{\left(\frac{\Delta}{\Delta - 1}\right)^2},$$

and also $p = \frac{\Delta^2 - (\Delta - 1)^2}{\Delta^2 + (\Delta - 2)^2} \times \frac{200}{n}$ approximately.

For the calculation of the future increment per cent., the probable diameter after n years may be assumed to be $D + \delta$, and increment per cent. to be approximately $\frac{(\Delta + 1)^2 - \Delta^2}{(\Delta + 1)^2 + \Delta^2} \times \frac{200}{n}$.

Pressler has published tables showing the values of this percentage for different values of Δ from 2 to 300.

In the case of standing trees, of which only the increment of diameter at the base can be measured, and rarely, if ever, the height, the percentage of increase in volume cannot be determined with any very great accuracy. For such trees Pressler has drawn up a set of tables for determining, with the aid of the relative diameter, the rate of increase per cent. for five grades of height-growth. In order to determine the percentage with sufficient approximation without the aid of such tables, we must first find D and $d = D - \delta$ by measurement, and then the rate per cent. of increase in diameter $= p_d = \frac{D - d}{D + d} \times \frac{200}{n}$ (for a single year $p_d = \frac{100\Delta}{D}$), and the minimum increase per cent. of volume $p_v =$

$2 p_d$. In most instances p_v varies from $2\frac{1}{2} p_d$ to $3 p_d$, and in the case of trees enjoying a full height-increment and forming a canopied crop, $p_v = 3\frac{1}{2} p_d$.

In calculating the increment per cent. for a single year, we may employ BREYMANN's formula. On page 48 it has been shown that the increment on volume is approximately equal to

$$i = v \left(\frac{2\delta}{d} + \frac{\lambda}{l} \right)$$

$$\text{so that } p = \frac{i \cdot 100}{v} = 100 \left(\frac{2\delta}{d} + \frac{\lambda}{l} \right)$$

When there has been no increase in height,

$$p = \frac{200 \times \text{diameter increment}}{\text{Actual diameter}} = \frac{200 \delta}{d}$$

Another simple formula to use is that of SCHNEIDER, by which

$p = \frac{400}{Dn}$, D being the actual diameter in inches, exclusive of the bark, and n the number of annual rings in the last inch of growth. $\frac{2}{n}$ is obviously equal to one year's increase of diameter, and this figure can consequently be used in Breymann's formula above.

Both Breymann's and Schneider's formula give only the rate of increase per cent. of the basal area, and the rate of increase per cent. of volume must be obtained therefrom in different cases as follows:—

- (a) In the case of trees possessing vigorous upward growth and standing in a leaf-canopy, by multiplying by $1\frac{1}{2}$.
- (b) In nearly all other cases of canopied trees, by multiplying by a factor varying from $1\frac{1}{4}$ to $1\frac{1}{2}$.
- (c) In the case of isolated trees without any multiplication at all in many instances.

E. Stem analysis, or the determination of the course of the increment of the stem during the whole term of its life.

If any tree forms annual rings, the observation of these rings enable us to trace its life-history, to say when it was suffering from suppression, from insect ravages, from the effects of fire, frost and from other retarding causes, when it enjoyed complete immunity from such injurious influences, and was a dominant stem growing vigorously, and so on. A longitudinal section passing through every point of the axis of the stem would show all this at a glance, but such a section is practically impossible to make; the stem must be cut across into a number of sections, and the required information sought thereon. The sections may be made at every 6 feet, but as a tree grows fastest when young, the lower sections may be longer (up to 10 and even 14 feet in the case of quick-growing trees), while the upper ones may be made shorter. The first cross-cut should be made at

the usual height of $4\frac{1}{2}$ feet off the ground,* but there will always be a lower one than this at the level at which the tree has been felled.

The measurement of the diameters and the counting of the rings are operations which take time, and will generally be best effected in camp or at home. For this purpose a disk about 1 inch thick should be cut off the lower end of each section, and carried away to be studied at leisure. To prevent mistakes, the serial number of the tree and corresponding section and other necessary information should be noted on the upper surface of each disk as soon as it has been cut.

The lowest section serves to determine the age of the tree, and the other sections the successive ages of the tree at the heights at which they have been cut. On all of them the annual concentric growths should be marked off in groups of 5 or 10, beginning at the circumference. The outer diameter of each such zone (of 5 or 10 years' growth, as the case may be) should then be measured, and recorded in the manner shown in the illustration given lower down. The observer should be careful that the 5 or 10-year groups, marked on the several sections, exactly correspond. Thus, for instance, the first groups of all the several sections should contain concentric rings of one and the same age; the rings of the second groups should be exactly 5 or 10 years younger, and so on. To guard against error in forming the groups, extremely broad or extremely narrow rings should be carefully noted and traced through all the sections.

With the help of the figures obtained from the observations just described, a longitudinal section of the stem can be delineated, showing the whole course of growth. The scale for diameters should be from 10 to 20 times larger than that for heights. A central line being drawn to represent the axis of the tree, the lengths of the sections should be marked off on it according to the fixed scale. At each point of division parallel lines at right angles to the axis should then be drawn, and the measured outer diameters of the respective concentric group-zones pricked off on them. The required section of the tree is completed by joining by a continuous line or curve all the points corresponding to the same age.

The rapidity of growth in height of the tree may be delineated by means of a curve, as described at page 52 of Part I of Fernandez's *Manual of Indian Sylviculture*. Distances should be marked off along a horizontal line representing periods of 5 or 10 years, as the case may be. At these divisions perpendiculars

should be raised, the lengths of which should correspond with the heights successively attained at the different ages. A continuous line joining the upper extremities of these perpendiculars will be the required curve. The horizontal scale for years should be about twice the vertical scale for feet.

The contents of the tree at the successive ages (every fifth or tenth year, as the case may be) are at once ascertained from the sectional areas enclosed by the outer boundaries of the concentric group-zones, each sectional area being the mean sectional area of a truncated cone; situated half in the upper half of one section, and the other half in the lower half of the one immediately above it.

Finally, the periodic increments of diameter, height and volume can be arranged in tabular form so as to be noted at a glance.

We will illustrate all the preceding remarks by means of an example.

A spruce was felled at 3 inches above the ground, and the stump showed 43 annual rings. We may assume that the tree took two years to attain this height, and it is on record that it was sown 45 years ago. The total length of the tree was 64 feet, the stem was cut up into lengths of 6 feet each, except the lowest portion, which was 4 feet long. On all the sections, beginning from the circumference, the annual rings were marked off into groups of five each along three different diameters on the two lowest sections (at $\frac{1}{4}$ and $4\frac{1}{4}$ feet from the ground), and along two diameters crossing each other at right angles on the rest. For each section the mean of the two or three diameters, according to the piece, was taken. The results of the observations are shown in the following statement:—

Section.		Total number of annual rings.	Mean diameter in inches at the age of—										Mean diameter with bark.
Serial number.	Height in feet.		5	10	15	20	25	30	35	40	45		
			Years.										
1	1 $\frac{1}{4}$	43	0.51	1.42	3.70	5.82	7.53	8.60	9.79	10.17	12.40	12.87	
2	4 $\frac{1}{4}$	37	...	0.39	2.55	4.50	5.92	6.84	7.68	8.61	9.40	9.80	
3	10 $\frac{1}{4}$	33	...	...	1.57	3.70	5.40	6.44	7.36	8.30	9.03	9.43	
4	16 $\frac{1}{4}$	30	...	...	...	2.07	4.20	5.59	6.69	7.66	8.44	8.80	
5	22 $\frac{1}{4}$	26	...	...	...	0.35	2.52	4.31	5.74	6.92	7.89	8.25	
6	28 $\frac{1}{4}$	23	...	...	...	...	1.39	3.33	5.05	6.42	7.35	7.74	
7	34 $\frac{1}{4}$	19	...	...	...	...	...	1.83	3.91	5.61	6.68	7.01	
8	40 $\frac{1}{4}$	16	...	...	...	...	...	0.59	2.59	4.53	5.87	6.22	
9	46 $\frac{1}{4}$	12	...	...	...	...	...	...	1.01	3.10	4.67	4.98	
10	52 $\frac{1}{4}$	9	...	...	...	...	...	...	...	1.88	3.64	3.86	
11	58 $\frac{1}{4}$	6	...	...	...	...	...	...	...	0.39	1.88	2.10	

CALCULATION OF VOLUMES ACQUIRED SUCCESSIVELY AT 5, 10, 15.....45 YEARS OF AGE.

Height of section in feet.	Area in square feet at the age of—										Area in square feet at 45 years with bark.
	5	10	15	20	25	30	35	40	45		
	Years.										
4½	...	...	0.0358	0.1104	0.1923	0.2531	0.3223	0.4757	0.4794	0.5251	
10½	...	...	0.0133	0.0742	0.1576	0.2260	0.2966	0.3769	0.4418	0.4858	
16½	...	...	...	0.0232	0.0956	0.1688	0.2439	0.3223	0.3883	0.4236	
22½	...	...	...	...	0.0841	0.1014	0.1803	0.2625	0.3382	0.3712	
28½	...	...	...	...	0.0103	0.0598	0.1398	0.2260	0.2966	0.3276	
34½	...	...	...	...	...	0.0179	0.0846	0.1726	0.2439	0.2873	
40½	...	...	...	...	...	...	0.0358	0.1104	0.1883	0.2083	
46½	...	...	...	...	...	...	0.0055	0.0333	0.1198	0.1364	
52½	...	...	...	...	...	...	...	0.0192	0.0717	0.0819	
58½	...	...	...	...	...	...	...	...	0.0192	0.0232	
Total area in square feet of sections of the same age . . .	...	...	0.0491	0.2078	0.4899	0.8270	1.3088	1.9489	2.5872	2.8509	
Contents in cubic feet of the 6-foot lengths at the successive ages . . .	...	...	0.29	1.25	2.94	4.96	7.85	11.70	15.62	17.10	
Contents in cubic feet of the lowest 1½ foot length at the successive ages . . .	...	...	0.05	0.15	0.24	0.32	0.41	0.48	0.65	0.70	
Contents in cubic feet of top end at the successive ages . . .	0.001	0.026	0.013	0.008	0.001	0.004	...	...	...	0.016	
Total contents in cubic feet of tree at the successive ages . . .	0.001	0.026	0.35	1.41	3.18	5.28	8.26	12.18	16.17	17.82	

TABLE SHOWING COURSE OF INCREMENT OF THE STEM.

Age in years.	Diameter in inches.		Height in feet.		Volume in cubic feet.		Form-factor.		Increment of volume per cent.
	Actual.	Increment.	Actual.	Increment.	Actual.	Increment.	Ordinary.	Absolute.	
5			2		0.001				
10	0.4		7		0.026				
15	2.6	2.2	16		0.35				
20	4.5	1.9	24		1.41		0.529	0.472	24.0
25	5.9	1.4	33		3.18		1.77		
30	6.8	0.9	42		5.28		2.10		
35	7.7	0.9	50		8.26		2.98		
40	8.6	0.9	59		12.18		3.92		
45	9.4	0.8	64		16.17		3.99		
Inclusive of bark,	9.8		64		17.82		0.536	0.509	

3. Rate of increase of crops.

In the case of crops it is obvious that we require to know only the rate at which the volume of the crop increases, and that a knowledge of the rates at which the height of the crop and the aggregate diameters and basal areas of the component stems increase, is of interest only so far as these elements are so many factors in the growth of the crop.

A. Determination of the increment at any time.

There are various methods of determining the rate at which a crop has been augmenting in volume at any time. They are—

- I. BY MEANS OF INVESTIGATIONS IN THE CROP ITSELF.—In determining the increment it must never be forgotten that no one class of stems can be taken as representative of the whole crop, any more than any individual stem

can be taken as representative of its class. It must also be borne in mind that so far as the standing timber alone is concerned, thinnings cause the rate of increase to fall. Lastly, we have the fact that what is now an average stem of the crop was at one time an overtopping or dominant tree, and may in the future become a dominated or overtopped or even a suppressed one.

The simplest way of determining the increment of a crop with the nearest approximation is to determine first the percentage of increase of several stems of each and every component class. If the crop is at the time under a regular valuation survey, this percentage is calculated for the section passing through the middle of the felled sample trees, and the data thus obtained should also be supplemented by measurements made on standing trees. If there is no valuation survey going on, then measurements made on standing trees must supply all the required data.

If $V_1, V_2, \dots$ have been ascertained to be respectively the volumes of the several stem-classes, and $p_1, p_2, \dots$ their average increment per cent., then the increment for one year (i) of the several classes will be, $i_1 = \frac{V_1 p_1}{100}$;

$i_2 = \frac{V_2 p_2}{100} \dots \dots \dots$ and the total increment of the crop

$= I_s = i_1 + i_2 \dots \dots \dots$;

so that the increment per cent. of the crop will be

$$= p_s = \frac{100 I_s}{V_1 + V_2 + \dots}$$

The formula just investigated should be used only when it is required to know the increment for a single year, or for a short period. If it is sought to determine the increment for a long period of n years, another procedure must be adopted. $p_1, p_2, \dots$ being found to be the percentages of increase of the respective stem-classes during this period, the volumes $v_1, v_2, \dots$ of these classes n years ago may be determined from Pressler's formula thus—

$$v_1 = V_1 \frac{200 - np_1}{200 + np_1}; v_2 = V_2 \frac{200 - np_2}{200 + np_2}; \dots$$

The increment for the n years will hence be—

$$I_n = (V_1 + V_2 + \dots) - (v_1 + v_2 + \dots).$$

Lastly, if it is required to ascertain the probable increment for the next n years, we must determine the probable volumes $V'_1, V'_2, \dots$ of the several stem-classes at the end of n years by the same formula of Pressler's

$$V'_1 = V_1 \frac{200 + np_1}{200 - np_1}; \dots$$

The increment for the n years will be

$$I'_n = (V'_1 + V'_2 + \dots) - (V_1 + V_2 + \dots) = V'_s - V_s.$$

The rate per cent. of increase for the same period will be—

$$p'_n = \frac{V'_s - V_s}{V_s} \times \frac{220}{n}.$$

From all the preceding expressions it will be obvious that the increment per cent. of the whole crop can be equal to the arithmetical mean of the percentages of increase of the sample stems only when $V_1 = V_2 = V_s, \dots$, and this mean will be approximately correct if the number of sample stems is very large and they are mostly taken from the dominant class.

- II. WITH THE AID OF PERCENTAGES THAT HAVE BEEN PREVIOUSLY OBTAINED FROM ACTUAL INVESTIGATIONS IN SIMILAR CROPS.—In this case three facts have to be borne in mind, *viz.*, (1) that the percentage of increase falls as the age of the crop increases, and can be assumed as constant only for short periods; (2) that the percentage falls more rapidly, the more quickly the individual trees increase in diameter and volume (crops of poor upward growth yield a higher percentage than vigorous crops of equal age); and (3) that the lighter crop has a larger percentage than the denser one.

This method is employed in open crops and coppice standards in neither of which cases are tables of yield directly applicable.

- III. WITH THE AID OF TABLES OF YIELD.—When such tables are used, the locality, density and age of the crop in question and of the crops from which the tables have been calculated must correspond very closely.

- IV. BY ASSUMING THE INCREMENT SOUGHT TO BE THE MEAN ANNUAL INCREMENT AT THE PRESENT AGE OF THE CROP.—This method is applicable to exploitable crops.

- B. Determination of the mean increment of a crop for the entire period in which it reaches exploitability.

In the case of all crops that are nearly exploitable the mean increment at the present age is for all practical purposes the mean increment sought. It is only in very old crops that the present mean increment will be found to be too small: For very young crops, and in crops much younger than the age of exploitability, the required mean increment must be obtained from yield tables.

- C. Course of the increment of a crop during the whole period of its life.

The stem-analysis (see page 53) of the sample stems can give the course of growth solely of the present main crop (*i.e.*, the crop exclusive of the overtopping, overtopped and suppressed stems), and as regards the crop at previous ages it can furnish only the volume and height of the largest trees which the crop then contained. Hence, to be able to trace the course of growth of a crop through its successive ages, the same crop must be successively surveyed at each of those ages.

- D. Which method of determining the increment of crops to employ according to the purpose for which the information is required.

The determination of the increment of entire crops is generally undertaken for the purpose of framing working-plans, and the object then is to ascertain either what the yield of the several crops will be when they are felled, or at what respective ages they will severally become exploitable.

When it is required to determine the mean annual increment of a crop up to the time it becomes exploitable, yield tables should be used if the crop is young, and the formula $\frac{\text{present volume}}{\text{present age}}$ if the crop is nearly exploitable.

When it is required to know what a crop will yield if it is felled within the next 20 years, we must add to the present volume the probable increment for the ensuing 5 or 10 or even 15 years. This increment may be determined either (1) as a percentage in the crop itself, or (2) by adopting such percentages as usually accrue in similar crops at the age of the highest mean increment, or (3) by adopting the mean annual increment of the given crop at the present age, or (4) by using the increment furnished by yield tables.

In some methods of framing working-plans it is necessary to know what the yield at the time of felling will be of all the crops,

from the youngest to the oldest. This information can be obtained only with the help of yield tables.

Whether a given crop is exploitable or not must be determined by the fact whether the percentage of increase demanded is being produced by the crop. This can be settled only by investigations in the crop itself.

4. General remarks on the course of development of the individual tree.

The following remarks apply only to seedling trees and not to coppice shoots:—

A. Growth in height.

The growth in height is at first nearly always very slight, and in India remains so, according to the species and to the soil and locality, for a period extending from 3 to 10 and even 15 and up to 20 years. During this time the seedling is technically said to be establishing itself. As soon as the seedling is thoroughly established, the rate of growth in height increases rapidly, and attains an annual maximum in a comparatively short time. In Europe this maximum is attained in the case of pines and larch in 10-15 years, in the case of the spruce in 20-25 years, and in the case of the beech and silver fir in 30 years. For India we have unfortunately no exact figures, and owing to the continental variety of its soils and climates, one and the same species presents extremely wide divergences. The maximum rate of growth only lasts a short time. The rate sinks rapidly in the case of species in which the maximum is attained early, more slowly in others, until it is reduced to from 3 to 6 inches a year, at which figure it keeps for a great number of years. A total cessation of growth in height occurs only at a very advanced age, and earliest in isolated trees.

Rapidity of upward development reaches its maximum earliest and begins to fall quickest in the most favourable soils and localities. In unfavourable localities, as on mountain ridges, the rate at which a tree grows up remains nearly constant during its whole life, after it has once attained a certain figure. In youth and middle age the rapidity of growth in height in the most favourable localities exceeds greatly that in unfavourable ones; afterwards there is but little difference. The height reached by trees in mature crops is from two to three times as great in favourable loca-

lities as in unfavourable ones. It has been recently established that a close leaf-canopy not only checks growth in girth but also growth in height, although the latter is not influenced by the density of the crop to the same extent as the former, and the unfavourable influence begins to show itself only in very dense crops.

B. Growth of girth and basal area.

The course of growth of the girth at ground level is similar to that of the height of the tree. The girth is, however, usually measured at breast-height ($4\frac{1}{2}$ feet). Hence a curve delineating its growth cannot start from zero, but from the point of time at which that height was attained. By the time a tree reaches this stage, the rate of growth of the girth has either entered upon its maximum or is on the point of doing so. Therefore, as we are accustomed to measure it; the girth starts at or near its maximum rate of increase. When the rate of growth begins to decline, it does so, at first more or less rapidly according to species, soil and locality, slowly afterwards, and remains more or less constant for some time.

The rate of increase of the basal area is very slight at first, then augments more or less rapidly up to a certain figure, after which it remains constant or diminishes slowly. The continuance of a dense leaf-canopy up to an advanced age results in an early and rapid decrease of the rate of growth of the basal area of the individual component trees. On the other hand, in the case of trees standing isolated, the rate of growth increases, or at least remains constant, beyond even the ordinary age of exploitability. In the most favourable soils and localities the rate of increase of basal area of the individual tree attains its maximum rapidly (about the 40th or 50th year for European trees) and then declines; whereas under opposite conditions it augments slowly, but the augmentation continues up to a great age.

C. Development of the form-factor.

The development of the form-factor of a tree is dependent on the rate of increase of the girth at different heights, which rate itself depends on the amount of standing room and the consequent expansion of the crown. In the case of trees forming a leaf-canopy the width of the annual rings of growth is generally greatest at the

top, and diminishes downwards to some point close to the ground, and then increases again down to the crown of the roots. The rings are thus narrowest at a certain point in the lower part of the stem, which point is almost on a level with the ground in young trees, but gradually moves upwards with increasing age and the formation of buttresses. In exploitable trees this point is generally situated above the usual height of measuring the diameter, *viz.*, 4½ feet; and in very old trees, and in those which possess free growing-room, it is found as high as 12 to 24 feet above the ground.

The increasing width of the annual rings from bottom upwards is most marked in favourable soils and localities and in trees in the midst of a dense leaf-canopy (*i.e.*, trees with a long bole and a small high crown), and least so in unfavourable soils and localities and in overtopping and, especially, isolated trees. It is also most conspicuous in trees that are growing up vigorously, and this particularly in the upper part of the stem, whereas, on the contrary in trees pushing up slowly or which have entirely ceased to grow, the width of the rings diminishes again towards the top. In the case of isolated trees with low-spreading branches the rings are of the same width throughout the entire length of the stem, or may even become narrower from bottom upwards.

Young trees have an absolute form-factor of from 0.30 to 0.35. With increasing age these figures rise to 0.44 and even 0.48; but they ultimately diminish after an advanced age is reached. This decrease occurs in the European larch at the age of 80—100 years, and even earlier in trees grown out in the open. Trees that have developed in isolation always have a low form-factor. In favourable soils and localities the form-factor is higher than in unfavourable ones.

- The rate at which the stem expands at different heights is obviously not the same as that at which the girth increases. The increment of sectional area is greatest at the level of the soil, decreases rapidly upwards for a short distance, then much more gradually up to the beginning of the crown (sometimes even increasing in the vicinity of the crown), and lastly, diminishes very rapidly upwards to the top of the crown, where it consists merely of the sectional area of the previous season's shoot. In trees growing in the midst of a dense leaf-canopy, and in those already dominated, the largest increment of sectional area occurs in the

upper part of the bole; whereas in isolated trees it is to be found much lower down. In canopied crops growing in favourable soils and localities the increment of sectional area is almost the same throughout the entire length of the stem; in unfavourable soils and localities and in the case of all isolated trees, whatever the nature of the soil and locality, it steadily decreases from below upwards.

D. Rate of increase of volume.

Increased mass is the result of the co-operation of three factors— increase of height, increase of girth and augmentation of the form-factor. In early youth, in spite of the great width of the concentric rings of woody growth, the increment of volume is small; it reaches an important figure only when the crown has acquired some development, and the stem, by its increased height and girth, presents a sufficiently extended surface for the deposit of new woody growth. After this period the rate at which the volume increases rises rapidly to its maximum. In Europe this maximum is attained at the age of 50—70 years in the case of quick-growing species in suitable soils and localities; at the age of 100—120 years in the case of slow-growing species under unfavourable conditions; and at a very advanced age by trees standing out in the open, or situated on high exposed ridges or at great elevations. Once at its maximum, the annual rate of increase remains more or less steady for a long time, after which it declines, but at a less rapid rate than that at which it rose.

The mean annual increment of the individual tree, as a rule, attains its maximum only at a very advanced age, generally beyond that of ordinary exploitability. Even in canopied crops the maximum is not reached by the dominant and over-topping trees before the age of 120—140 years. Trees growing out in the open, and individuals of species which develop slowly during their youth, attain it much later; while in high mountainous regions many trees as much as 300 years old may be found which have not yet entered upon that stage.

5. General remarks on the growth of the crop.

The course of development and the accretion of volume in timber crops depends not only on the species, soil and locality, but also on the treatment and system of working adopted. In respect of one and the same species the amount of production is influenced chiefly

by the soil and locality, the course of development of the crop by the treatment and system of working. Of the course of growth in crops worked by the jardinage and coppice methods but little is as yet known, but a flood of light has been thrown on the growth of regular crops treated by the uniform method by the labours of the German Department for Forest Research. The remarks which follow refer only to such crops.

A. Natural constitution of stem-classes.

In every crop we can recognise, besides the over-topping and dominant individual, two lower classes of dominated and over-topped ones, and, if no thinnings have been made, also a fifth class of suppressed stems. The first two classes form what may be called the main crop, the other three the subordinate crop. It is obvious that in the ordinary course of development of the crop fresh stems are constantly passing into the lower classes from the immediately upper ones, and from the main crop into the subordinate one, from which they are ultimately removed by thinnings or natural decay and death. The result is a constant diminution of the number of stems composing the main crop.

The original number of individuals in a crop depends on the manner of its constitution, according as it has sprung up from self-sown seedlings or from artificial sowing (generally executed close), or from transplants (generally put out comparatively far apart). The number of stems diminishes rapidly in youth, less rapidly in middle age, and still more slowly in old age; rapidly in favourable soils and localities; slowly, but steadily, up to a great age in unfavourable places. At one and the same age more stems stand in unfavourable soils and localities than in those more suitable. A crop of Scotch pine of the best quality contains 1,200 stems per acre at 30 years of age, but only 140 stems 90 years later at the age of 120 years.

This constant and great diminution in the number of component individuals results in a considerable falling off of the increment, the consequence being that both the current and mean annual increments reach their culminating point earlier in the case of the crop than in that of the individual belonging to the dominant or representative class.

Since thinnings and decay and death remove mostly the indivi-

duals of the lowest class, the average stem of the crop is constantly moving upwards into one of the (up to the present) larger stem-classes, and on the other hand the average stem at any given age is constantly receding into a smaller class and ultimately takes its place in the subordinate crop. So that the exploitable crop eventually consists for the most part of individuals which in their youth belonged to the highest or over-topping class. Hence investigations into the course of growth of a crop, by means of measurements and ring-countings made on existing already exploitable individuals, give the heights, diameters, basal areas, volumes, etc., at various periods, not of the representative or average individuals at those periods, but of the largest class of stems of those periods.

B. Basal area.

According to the universal convention adopted of measuring the diameter at breast-height ($4\frac{1}{2}$ feet), the basal area of crop is obviously *nil* until that height is attained; it then increases rapidly up to middle age, and thenceforward more slowly but steadily up to a great age. The diminution of the rate of increase is very conspicuous in the case of quick-growing or shade-avoiding species, but is comparatively slight in the case of shade-enduring or slow-growing species. Thus the basal area in good crops of the European spruce or silver fir, at the age of 140—150 years aggregates as much as 348 square feet per acre, whereas in the best crops of Scotch pine or beech it seldom exceeds 217 square feet per acre. In inferior soils and localities the basal area, for one and the same age, is considerably less than in good soils and localities in spite of the number of stems being larger. In Germany, in unfavourable localities, the basal area in mature crops is only 130 square feet per acre for pine and larch, and 196—217 square feet per acre for spruce and silver fir. In Germany the basal area of a crop is on an average about 0.5 per cent. of the area covered by the crop; in the best soils and localities the average percentage is 0.8 for spruce and silver fir.

C. Volume.

The volume of a crop, as well as the rate at which it increases, is very small in early youth. The volume then increases rapidly up to the end of the middle age of the crop, after which the rate of increase is much less rapid, but is maintained up to a very advanced

period. A complete cessation of increase can occur only when the increment of the growing stems is just counterbalanced by the loss due to decay and death.

◦ The current increment of volume becomes rapidly larger until it attains its maximum in 30—40 years in the case of quick-growing species under favourable conditions, and in 70—80 years in the case of slow-growing species and in unfavourable soils and localities. After reaching its culminating point, it sinks rapidly in places where favourable conditions exist, more slowly where circumstances are not so suitable.

The mean annual increment obviously begins by being identical with the increment of the first year. As the current increment now goes on increasing steadily year by year, as long as this increase continues, and also for some time afterwards, the mean increment obviously keeps below the figure of the current increment. Ultimately it catches up and gets ahead of the latter, and as the current increment goes on steadily declining, the mean increment maintains its superiority to the end. The mean annual increment obviously attains its maximum when it becomes equal to the current annual increment, for the continued diminution of the latter must cause it to decline also from that point. As the current increment diminishes only gradually, especially in unsuitable soils and localities, the mean annual increment, after attaining its culminating point, continues nearly at the same level for a considerable period, particularly so in unfavourable places, where this period may extend over several decades.

Chapter VII.

On the compilation of tables of yield.

In yield tables are collected figures representing the course of growth of different classes of crops that have developed under normal conditions of growth and density. These figures give the volume and increment per unit of area of the crops in question at different ages and under different conditions of growth, and sometimes also the corresponding factors which contribute to the production of volume, *viz.*, number of stems, basal area, and height of crop.

As shown higher up, the course of development of a crop cannot, like that of the individual tree, be deduced by a single series

of investigations made at the age of exploitability. The number of stems, the basal area, and the dimensions of the average stem at all previous periods must be known. Hence to trace the course of growth of a given crop it must be surveyed from its earliest youth annually, or at regularly recurring periods, until it becomes exploitable. This method of repeated survey has been adopted in order to measure the influence of different modes of treatment on crops that in all other respects are similar.

To follow out this system rigidly on one and the same crop through the whole of its life would be an extremely long and slow process. In order to curtail it and obtain the results sought as quickly as possible, several similar crops, under the same treatment but of different ages, are experimented upon, and the various observations made from time to time in the several crops are combined and interpolated together into a connected whole, that is nearly, if not quite, as accurate as if the figures it comprises had been obtained from investigations in one and the same crop from the time of its constitution to its maturity.

There is yet another and still shorter way of obtaining the requisite figures. A series of crops growing under similar conditions of species, soil, locality and treatment, but of various ages differing from each other by as short intervals as possible, is chosen with great discrimination and care, and each crop is measured once for all, the results being tabulated together. Most of the yield-tables hitherto compiled have been obtained by this method, and the results have been proved to be quite correct enough to justify its adoption as often as there is no time to wait for the outcome of the longer and more elaborate methods.

Whichever of the two last described methods is adopted, there are always certain ages for which figures are wanting, and the gaps must be filled up by interpolations which are most conveniently obtained graphically thus:—The various successive ages are marked on a horizontal line, and at these points perpendiculars are raised, the perpendiculars for the ages for which the volumes or increments are known being made of the lengths corresponding to these volumes or increments, as the case may be. The ends of these perpendiculars being joined by a continuous curve, the lengths of the other perpendicular up to where they are cut by the curve, give respectively the remaining volumes or increments.

The figures obtained for the volumes should be checked by constructing similar curves with the known numbers of trees, basal areas and heights, and obtaining by interpolation the corresponding figures for the other ages. The complete figures obtained for each series should then be compared: wherever discrepancies are found corrections can be easily made. Such a check for the volumes is best obtained by comparison with the figures obtained for the basal areas and heights, the products of which, multiplied by the respective form-factors, will furnish another series of volume figures. The form-factors used may be obtained at the same time as the other information.

The accuracy of yield tables is always more or less uncertain, owing to the difficulty of selecting the experimental crops so that they may be exact counterparts of each other at their own respective ages. The necessary correspondence is best secured by careful and detailed stem analyses in the older crops, in order that the heights of the dominant stems at earlier periods may be more or less exactly ascertained. The experimental crops for these earlier periods should then be so selected that their average heights correspond with the figures thus deduced.



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